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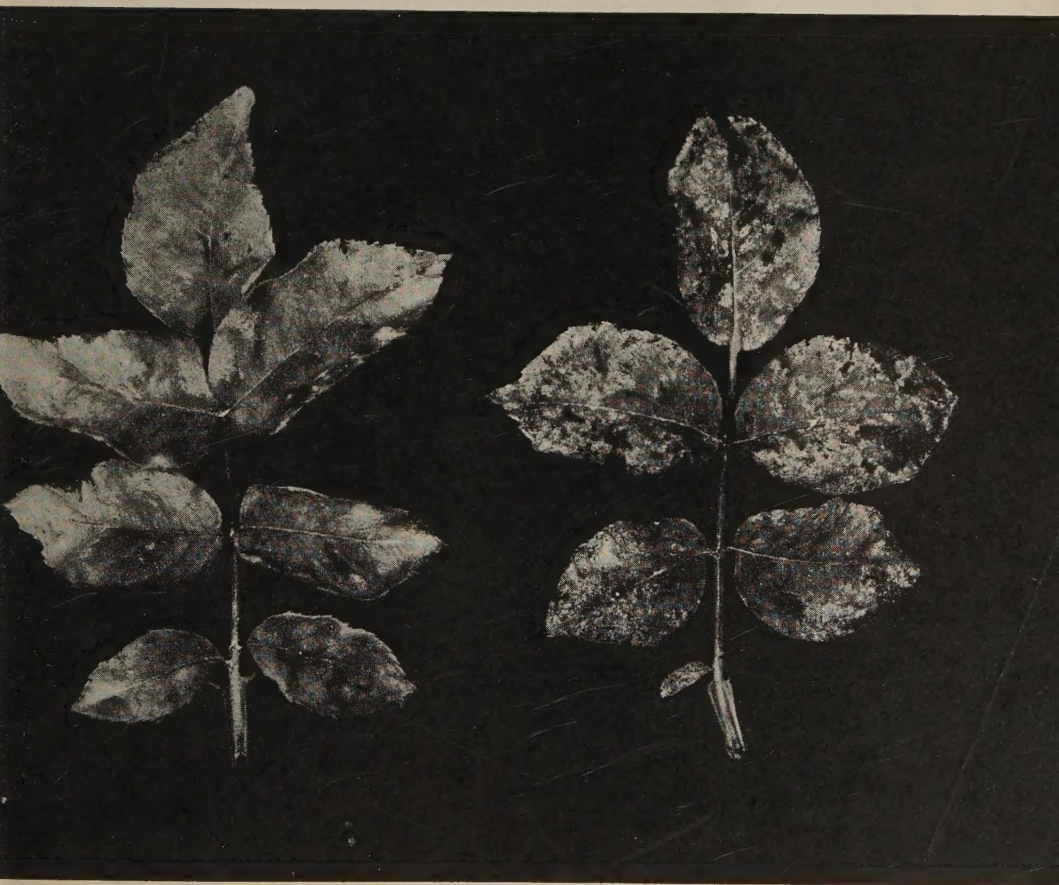
Control of Powdery Mildew of Roses in the Greenhouse

Wilbur Dwight McClellan



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CONTROL OF POWDERY MILDEW OF ROSES IN THE GREENHOUSE[1]

WILBUR DWIGHT MCCLELLAN

Powdery mildew, caused by the fungus *Sphaerotheca pannosa* (Wallr.) Lév. var. *rosae* Wor., has long been recognized as a serious disease of roses in the greenhouse. Its severity varies with environmental conditions, and recommended measures for its control are not wholly satisfactory. It is hoped that the information here presented will aid rose growers in avoiding losses due to this disease.

Longrée (1939)[2] concluded from her extensive investigations of the relation of temperature and humidity to the development of powdery mildew of roses, that this disease "cannot be effectively controlled under greenhouse conditions through regulation of temperature and humidity, but the disease may possibly be held somewhat in check by keeping both the temperature and humidity as low as is possible and feasible for the cultivation of roses and by avoiding drafts and extreme changes in temperature. Since these requirements are difficult to meet, except possibly during the winter months, the application of fungicides seems to remain an indispensable measure in the control of the disease." Therefore, an investigation of fungicides for the control of powdery mildew of roses was undertaken. Data concerning the use of fungicides, wetting agents, sulfur vaporization and syringing are presented herein.

COMPARISON OF FUNGICIDES

SPORE-GERMINATION TESTS

Methods and results. A large number of materials have been recommended for the control of powdery mildew, and others are constantly being advocated. Since it would not be practical to test all of these materials under commercial conditions, some laboratory method of eliminating all but the more promising had to be used.

A number of different methods have been proposed for the laboratory-testing of fungicides (McCallan, 1938), but nearly all of these methods involve the use of an artificial substrate without giving any consideration to the host tissue. Martin (1932), Marsh (1936), and Horsfall, Marsh, and Martin (1937) have pointed out that these techniques ignore any interaction of the leaf with the fungicide. Marsh (1936) is one of the few who have attempted to make spore-germination counts on sprayed leaves.

[1]Also presented to the Faculty of the Graduate School of Cornell University, June 1941, as a major thesis in partial fulfillment of the requirements for the degree of doctor of philosophy.

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[2]For a detailed account of the effect of temperature and humidity on powdery mildew of roses the reader is referred to the following publication: *The Effect of Temperature and Relative Humidity on the Powdery Mildew of Roses,* by Karla Longrée (Cornell Univ. Agr. Exp. Sta., Mem. 223: 3–43, 1939).

The present writer had to devise a method, using excised rose leaves, for the testing of fungicides since very poor and erratic germination of spores of *Sphaerotheca pannosa* var. *rosae* is obtained on glass slides except under carefully controlled conditions (Longrée, 1939).

The procedure used for comparing fungicides by this method was as follows: excised leaves were first washed in distilled water, allowed to dry, and the desired spray material was applied to both sides of the leaf with a hand atomizer. The leaves were again allowed to dry, and young conidia (conidia produced during the preceding twenty-four to forty-eight hours) were dusted on them. The petioles of the leaves were inserted in shell vials containing water, and were placed in moist chambers where they remained for twenty-four hours. At the end of this period, the percentage germination was determined by counting the spores *in situ* by means of a Leitz Ultropak microscope. Each material was studied in duplicate or in triplicate. Unsprayed leaves were used in each test as controls.

Sixteen compounds or mixtures containing sulfur, fourteen containing copper, and twenty miscellaneous materials were tested in this manner, using the concentrations recommended by the manufacturers or those recommended in the literature. The results of these tests are summarized in table 1. It will be noted from the data presented in this table that in a number of instances less than 100 spores were counted. In such instances, the results indicate trends only. The data do not necessarily mean that all of the materials tested either will or will not exhibit good fungicidal activity under commercial greenhouse conditions, but they do indicate the types of materials that might be expected to offer considerable promise under these conditions. Also, some of the materials that appeared promising in these tests may be eliminated (1) because of their toxicity to, or discoloration of, the rose foliage or blossoms, (2) because of their excessively high costs, (3) because they may be harmful to spray equipment, or (4) because of various other factors or combinations of factors.

The marked superiority of the protective action of the sulfur-containing materials is clearly shown in this table. Only three copper-containing materials—ammoniacal copper carbonate, Palustrex Sulfonate-B, and Eau Céleste—reduced spore germination 75 per cent or more as compared with the controls (considered as 100 per cent). Four of the miscellaneous materials — Helione Green, Helione Yellow, and malachite green, which are dyes, and Shirlan D, which contains salicylic anilide — reduced germination 75 per cent or more. All but one of the sulfur-containing materials gave equal reduction.

For a more critical comparison of fungicides by spore-germination tests, a method was devised whereby parts of the same leaflet were used in different tests as substrata for the germination of the conidia. Data presented in table 2 show the precision that can be attained by this method. For this particular experiment five healthy young leaflets of the variety Queen Mary were selected. Each leaflet was cut along the midrib, and each half was again divided into three approximately equal parts. One part of each leaflet was placed with the lower surface downward on moist cotton in each of six petri dishes. These petri dishes served as moist chambers. Thus, there was one portion of each of five different leaflets

TABLE 1. TOXICITY OF SULFUR, COPPER AND MISCELLANEOUS MATERIALS TO CONIDIA OF *Sphaerotheca pannosa* VAR. *rosae*

Fungicides*	Concentration	Fungicide		Checks		Per cent germination in relation to the respective checks
		Number of spores	Per cent germination	Number of spores	Per cent germination	
Sulfurs:						
Ansul Colloidal Sulphur	1:1200	355	11.5	367	77.6	14.8
Crystal Mildew Spray	1:90	476	18.5	330	69.3	26.7
Flotation sulfur	1:266	373	2.9	430	53.0	5.5
Ko-Sul	1:1200	76	0.0	49	71.4	0.0
Lime-sulfur	1:50	141	1.4	184	71.6	2.0
Lime-sulfur	1:100	124	0.8	155	75.4	1.1
Lime-sulfur plus ferrous sulfate	1:50 1:33	81	0.0	59	66.1	0.0
Lime-sulfur plus lead acetate	1:100 1:200	76	0.0	163	64.4	0.0
Potassium sulfide	1:270	319	2.5	347	65.3	3.8
Rosin mixture plus lime-sulfur	1:1000 1:500	156	0.6	161	69.5	0.9
Rosin mixture plus lime-sulfur	1:200 1:50	153	0.0	161	69.5	0.0
Selocide	1:400	87	1.2	90	67.8	1.8
Selocide plus Ko-Sul	1:800 1:800	12	0.0	90	67.8	0.0
Sulfocide	1:200	160	1.3	151	51.6	2.6
Sulfocol	1:100	300	0.3	391	73.2	0.4
Sulfur-rosin mixture	1:50	144	0.0	146	69.1	0.0
Coppers:						
Ammoniacal copper carbonate	.....	128	17.9	146	69.1	25.9
Bordeaux mixture	4–4–50	132	37.8	155	75.4	50.2
Bouisol White Oil Emulsion	1:100	493	66.3	409	81.7	81.2
Bouisol White Oil Emulsion	1:550	100	24.0	49	71.4	33.6
Burgundy mixture	4–4–50	98	31.6	171	71.3	44.3
Copper acetate	1:400	102	23.6	171	71.3	33.1
Copper hydroxide	1:85	64	37.5	163	64.4	58.3
Copper sulfate plus ammonium hydroxide	1:74 1:133	124	29.8	110	51.8	57.6
Copper sulfite	1:73	95	36.8	163	64.4	57.2
Cuprocide 54	1:3200	94	41.5	43	32.5	....
Cuprocide 54 plus gelatin	1:1600 1:350	258	50.0	409	81.7	61.2
Cuprocide 54 plus IN 438	1:1600 1:1000	584	29.6	592	81.8	36.2
Eau Céleste	.....	79	3.8	151	51.6	7.4
Palustrex Sulfonate-B	1:100	195	12.3	151	51.6	23.8
Soybean oil plus cuprous oxide (proprietary)	1:400	298	75.4	391	73.2	103.0
Miscellaneous:						
Cyclonox	1:400	685	54.5	467	69.2	78.8
8-hydroxyquinoline sulfate†	1:1000	321	22.4	616	50.5	44.4
Elgete	1:100	110	31.8	363	80.3	39.6
Helione Green	1:100	232	13.1	363	78.8	16.6
Helione Yellow	1:800	323	12.1	616	50.5	24.0
Kainit	1:10	245	20.0	452	64.6	31.0
Malachite green	1:5000	240	3.7	391	73.2	5.1
Nickel sulfate-lime mixture	2–2–50	64	20.3	87	73.5	27.6
Nursery Volck	1:500	284	64.1	318	67.2	95.4
Organic Fungicide No. 20	1:267	431	43.0	592	81.8	52.6
Ortho Mildew Spray	1:25	371	27.2	318	67.2	40.5
Phenothiazine	1:200	110	31.8	363	80.3	39.6
Potassium permanganate	1:400	58	43.1	59	66.1	65.2
Righto	1:400	210	64.8	592	81.8	79.2
R. S. 380	1:400	445	24.9	467	69.2	36.0
S. E. C. Oil	1:800	920	54.7	849	69.3	79.0
Shirlan D	1:500	254	5.9	352	64.8	9.1
Sodium arsenate	1:500	130	36.9	87	73.5	50.2
Sodium bicarbonate	1:130	81	33.3	59	66.1	50.4
Sodium carbonate	1:200	59	35.6	87	73.5	48.4

*See Appendix for the source and composition of the materials used in this study.
†Supplied by Eimer and Amend, New York City.

TABLE 2. PRECISION OF SPORE-GERMINATION TESTS IN THREE REPLICATED EXPERIMENTS IN WHICH CONIDIA WERE GERMINATED ON SIX PORTIONS OF EACH OF FIVE EXCISED ROSE LEAFLETS

Petri dish number	Replication	Number of spores germinated of each 100 counted				
		Leaflet number				
		1	2	3	4	5
1	a	70.0	78.3	85.1	79.3	75.0
	b	79.3	78.3	83.9	73.8	85.2
	c	88.9	84.1	87.6	86.5	88.0
2	a	69.8	83.1	87.1	85.9	75.6
	b	78.6	89.1	85.5	71.4	84.2
	c	89.2	91.0	88.4	86.7	85.2
3	a	65.8	85.7	74.7	79.0	72.3
	b	77.3	83.2	86.5	66.9	84.0
	c	90.8	83.2	91.4	88.5	93.0
4	a	64.5	79.9	88.6	89.7	69.9
	b	69.8	90.0	85.9	71.2	84.0
	c	95.6	86.3	86.6	94.2	90.0
5	a	69.6	81.3	81.7	87.8	71.5
	b	64.8	89.5	79.1	64.5	76.0
	c	92.8	84.2	89.4	92.1	90.8
6	a	71.6	79.4	87.3	81.7	76.8
	b	75.2	90.1	85.1	77.6	81.0
	c	92.0	80.0	91.5	84.4	86.3

Analysis of variance

	Sums of squares	Degrees of freedom	Variance
Total	5,363.57	89	.....
Petri dishes	71.27	5	14.25
Replications	1,889.62	2	944.81
Leaflets	646.51	4	161.63
Replications × leaflets	1,759.28	8	219.91
Petri dishes × replications	221.79	10	22.18
Petri dishes × leaflets	212.72	20	10.64
Remainder	562.38	40	14.06

Average germination of conidia*

Petri dishes	Leaflets	Replications
1. 81.553	1. 78.088	a. 78.267
2. 83.387	2. 84.261	b. 79.700
3. 81.487	3. 85.856	c. 88.623
4. 83.080	4. 81.178	.....
5. 81.007	5. 81.600	.....
6. 82.667	.....	.....

*There are no significant differences between any of the petri dishes. The least difference necessary to be significant for odds of 19:1 is 2.52 between leaflets and 1.96 between replications; to be significant for odds of 99:1, 3.38 and 2.62, respectively.

in each of the six petri dishes. The open petri dishes were then placed in the bottom of a five-gallon crock. Young conidia, not more than twenty-four hours old, obtained from actively sporulating lesions were dusted over the portions of the leaflets in the petri dishes, and these were incubated at 21°C. for twenty-four hours. The average spore concentration per square millimeter on these portions of leaflets was 14.4 ± 4.8. Three

replications of this experiment, one on each of three days, are included in this table. Each figure in the table represents the number of spores that germinated per 100 counted. The data were analyzed statistically by the analysis-of-variance method (Snedecor, 1937).

There was no significant difference between petri dishes, but the differences between leaflets and between replications were highly significant. There were no significant differences between the germination of the spores on different areas within a given leaflet: the average percentage germination of the spores on the halves of one side of the leaflets was 81.49 and that on the other side was 82.87; the average percentage germination of the spores on the portions of the tip of the leaflets was 82.32 while that of the spores on the base of the leaflets was 82.04. McCallan and Wilcoxon (1939), studying the precision of spore-germination tests with *Sclerotinia fructicola* on glass slides, found the greatest variance to be between replications made on different days. They concluded that the criterion to be used in comparing fungicides must be the consistency of their differences in different experiments. The same conclusion may be drawn from the data presented here. The data in table 2 show the day-to-day variation and also the effect of different leaflets on spore germination.

The data presented in table 3 illustrate the use of this method for comparing different sulfurs. Five sulfurs are here compared on the basis of their actual sulfur content. The same amount of sulfur was applied to portions of leaflets in each of five plates, the only difference between the plates being the sulfur used. Each of the suspensions of sulfur had an actual concentration of one part of sulfur in 2400 parts of distilled water. The materials were applied by means of a spray tower similar to the one described by McCallan and Wilcoxon (1940) to assure an equal distribution of the sulfur over all of the leaf portions. Their procedure for applying these sulfurs was followed except that the materials were atomized from the bottom of the tower and that petri dishes containing portions of rose leaves were substituted for glass slides. The leaves were given five one-minute exposures to the spray materials. This deposited sulfur on the leaves at the rate of approximately 6.0×10^{-6} grams per square centimeter. Each plate containing portions of five leaflets was sprayed with the desired material in this manner. The sixth plate was left unsprayed to serve as a check. After the spray suspensions had completely dried, young conidia were dusted on the leaflets as described (page 6), and the plates were incubated at 21°C. for twenty-four hours. At this time the number of spores germinating per one hundred spores counted on each portion of leaf was determined by the aid of the Ultropak microscope. This experiment was repeated on each of three days.

The variance obtained in this experiment is extremely large for both the treatments and the replications. The differences necessary for highly significant odds are small, which indicates that relatively small differences can be measured by this method. In this experiment the differences between treatments are all highly significant except that between Walcolized Sulphur and Protex Colloidal Sulphur.[3]

[3]These two sulfurs were very similar in character and may have been manufactured by the same process.

TABLE 3. COMPARISON OF THE TOXICITY OF FIVE DIFFERENT SULFURS TO CONIDIA OF *Sphaerotheca pannosa* VAR. *rosae* WHEN EXCISED ROSE LEAVES WERE USED AS THE SUBSTRATE FOR SPORE GERMINATION

(The sulfur concentration on the leaves was 6.0×10^{-6} grams per square centimeter)

Leaflet number	Replication	Number of spores germinated of each 100 counted					
		Check	Sulfur used				
			Walcolized	Protex Colloidal	Flotation	Fungisul	"Mike" Wettable
1	a	90.0	53.2	59.6	40.3	33.1	47.1
	b	81.0	50.3	39.1	29.8	12.1	36.5
	c	91.8	43.6	40.5	25.0	18.4	32.1
2	a	76.5	44.6	49.2	30.7	24.8	39.1
	b	76.1	29.8	18.7	10.5	5.9	10.8
	c	88.1	47.8	54.1	32.6	31.0	38.8
3	a	76.1	42.6	40.0	28.1	22.6	38.2
	b	76.0	31.8	23.1	15.2	2.6	14.7
	c	87.5	44.6	44.1	19.4	11.3	35.1
4	a	75.4	41.5	31.3	26.9	20.5	31.1
	b	63.7	18.1	16.3	7.7	5.9	7.1
	c	86.5	41.1	45.7	25.2	24.4	37.6
5	a	62.0	36.5	30.9	22.5	19.8	26.6
	b	61.9	25.2	11.8	8.7	5.3	23.0
	c	78.4	37.6	48.0	16.8	19.4	36.8
Averages*.....		78.07	39.22	36.83	22.63	17.14	30.37

Analysis of variance

	Sums of squares	Degrees of freedom	Variance
Total.....	44,978.99	89	.....
Treatments.....	35,046.69	5	7,009.338
Leaflets.....	2,178.04	4	544.510
Replications.....	4,575.69	2	2,287.845
Treatment × leaflet.....	426.71	20	21.336
Leaflet × replication.....	1,303.10	8	162.888
Replication × treatment.	795.75	10	79.575
Remainder.....	653.01	40	16.325

*The least difference between treatments necessary for odds of 19:1 is 2.981 and for odds of 99:1 is 3.988

In table 4 the day-to-day variation in the three replications is more clearly shown. It will be noted that with but one exception the toxicity of each material is in the same order in each replication. The data obtained on the first and on the third days agree very closely.

On the basis of the data presented, the author concludes that this method is reliable and can be used for the laboratory-testing of the toxicity of protective fungicides for use in the control of powdery mildew of roses. The method may well be adapted for comparing fungicides on the leaves of other species of plants and employing other organisms.

Action of fungicides on Sphaerotheca pannosa var. rosae. Sulfur, copper, and various other materials have been recommended for the control of powdery mildew of roses. The general conception has been that powdery mildews and many rusts are "sulfur sensitive" rather than "copper sensitive". A number of hypotheses have been advanced to explain the manner in which sulfur and copper act on fungi. These hypotheses have been re-

TABLE 4. EFFECT OF FIVE DIFFERENT SULFURS ON THE PERCENTAGE GERMINATION OF CONIDIA OF *Sphaerotheca pannosa* VAR. *rosae* ON EXCISED ROSE LEAVES IN REPLICATED TESTS ON THREE DIFFERENT DAYS

(The sulfur concentration on the leaves was 6.0×10^{-6} grams per square centimeter in each case)

Material	Number of spores germinated of each 100 counted			
	First day	Second day	Third day	Average
1. Check	76.0	71.7	86.5	78.1
2. Walcolized Sulphur	43.7	31.0	42.9	39.2
3. Protex Colloidal Sulphur	44.2	21.8	46.5	36.8
4. Flotation sulfur	29.6	14.4	23.8	22.6
5. Fungisul	24.2	6.4	20.9	17.1
6. "Mike" Wettable Sulfur	36.4	18.4	36.1	30.4

viewed by Wilcoxon and McCallan (1930), McCallan and Wilcoxon (1931), Greaney (1934), Martin (1940 b) and others for the action of sulfur. McCallan (1930) and Martin (1940 b) have summarized the theories pertaining to the action of copper.

The current concept of the fungicidal activity of sulfur is that sulfur vapor diffuses to the spores where, in contact with living matter, it is thought to be reduced within the spore to a toxic sulfide, probably hydrogen sulfide. A few consider sulfur itself to be the toxic agent. Goldsworthy (1928) has shown that the polysulfides of lime-sulfur may be directly absorbed by spores, with the formation of elemental sulfur. McCallan and Wilcoxon (1931) have conclusively shown that the toxic action of sulfur may be exerted when sulfur is "at a distance" from a fungus spore.

The toxicity of copper sprays, on the other hand, depends upon soluble copper which, if not already present in the spray in a lethal concentration, may be brought into existence by the action of spores upon insoluble copper residues. Thus, spores may bring about their own death by the rapid absorption of copper from "insoluble" copper spray residues. Therefore, the action of copper differs from that of sulfur in that copper must be in solution to exert its toxic action, whereas sulfur may exert its toxic action when either in solution or in the elemental state. This may account for the greater effectiveness of sulfur than of copper as a protectant for the control of powdery mildew of roses, since conidia of *Sphaerotheca pannosa* var. *rosae* germinate very poorly in free water (Longrée, 1939) and nearly all infection takes place in the absence of free water.

A simple laboratory experiment was designed to test this hypothesis. For testing any one material each of four young rose leaflets was cut into three approximately equal parts, and one portion of each leaflet was placed with its lower surface downward on moist cotton in each of three petri dishes. Five one-minute exposures to the spray mixture in the spray tower were applied to one of the plates. This was allowed to dry on the leaflets, after which conidia were dusted over the portions in the three plates simultaneously. An equal amount of the same mixture was then applied to the second plate in a like manner and also allowed to dry on the leaflets. The third plate remained unsprayed to serve as a control on the other two. Thus, the conidia on the leaf portions in the first plate were in contact with the dried spray residue such as they would encounter

in a protective spray, while conidia on the leaf portions in the second plate were in contact with the liquid spray mixture during the short time required for the material to dry (about three to five minutes). The spores were incubated at 21°C. for twenty-four hours, at the end of which time the percentage germination was determined.

Ten materials, including a particulate sulfur, soluble and insoluble coppers, and silver, were tested in this manner in duplicate experiments on different days. Another series was studied, using distilled water alone as the spray solution to serve as a check on the method. The results of these tests have been summarized in table 5 under the headings of *check,* for the controls; *protection,* for the percentages of spores germinating on the leaflets in the first plates; and *eradication,* for the percentages of spores germinating on the leaflets in the second plates.

TABLE 5. EFFECT OF LIQUID AND DRY MATERIALS ON THE GERMINATION OF CONIDIA OF *Sphaerotheca pannosa* VAR. *rosae* ON EXCISED ROSE LEAFLETS

(Figures indicate percentage germination of spores)

Material and concentration	Checked (unsprayed)	Protection (material was applied and allowed to dry *before* conidia were dusted on leaflet)	Eradication* (material was applied and allowed to dry *after* the conidia had been dusted on leaflet)
Walcolized Sulphur 1:1200	83.7	35.9	39.8
Copper sulfate 1:2400†	76.0	66.1	20.6
Bordeaux mixture 4–4–50	85.3	78.9	22.6‡
Cuprocide 54 1:3200	76.3	62.5	61.1
Bouisol White Oil Emulsion 1:100	87.9	48.0	16.6
Silver mixture	92.1	73.6	45.2
Malachite green 1:5000	79.6	71.9	26.9
Helione Yellow 1:4000	83.9	60.6	23.0
Sodium carbonate 1:200	89.3	61.6	25.2
R. S. 380 1:400	79.1	54.0	31.9
Distilled-water check	79.8	76.9	79.8

*The conidia in the tests summarized in this column were in contact with the liquid spray material before they germinated. Since the germ tubes had not penetrated into the leaf tissues at the time the conidia came into contact with the liquid, this cannot be considered true eradication.

†Expressed as concentration of copper.

‡Few normal spores were present on the leaves treated with bordeaux mixture and most of those present were shriveled at the time spore counts were made. This may have been due to the dehydration of the spores by the lime. The spores shriveled only when they were sprayed after they had been dusted on the leaflets.

One material cannot be strictly compared with another in this table since different materials were tested on different days and since different spore populations and leaflets were used. The data do confirm, however, the accepted theories of the action of sulfur and copper. For example, it will be noted from the data that sulfur was just as effective in the presence or absence of free water, while the materials containing copper had little or no effect on spore germination in the dry state but exerted a marked effect when the copper was in solution. Cuprocide 54, however, being an "insoluble" copper, had very little effect in either case. Apparently not enough time elapsed during the drying of the "eradication" spray to bring sufficient copper into solution to become toxic. The reaction of Bouisol, a proprietary copper oxychloride in a white oil emulsion, was similar to that of both copper and sulfur; it reduced germination appreciably in both cases but more so in the case of the "eradication" spray. The silver mixture reacted similarly to the soluble coppers. The two dyes (malachite green and Helione Yellow), sodium carbonate, and R. S. 380 reacted as did the soluble

coppers, although their protective action was slightly greater than that of the coppers.

On the basis of these data, the writer concludes that it is erroneous to speak of *Sphaerotheca pannosa* var. *rosae* as a *sulfur-sensitive* organism. However, the data do indicate that sulfur materials should be much more effective than copper materials when they are used in protective sprays. On the other hand, both sulfur and soluble copper, as well as the other soluble materials tested, should be effective when used in eradicant sprays for the control of powdery mildew of roses. Insoluble coppers should not be nearly so effective as soluble coppers in eradicant sprays.

TESTS IN COMMERCIAL GREENHOUSES

A number of tests to compare the effectiveness of different fungicides as protectants and as eradicants have been made under commercial greenhouse conditions.

A test was conducted to compare the protective action of various sulfurs and of copper. Two different houses in the same greenhouse range, one containing Talisman roses and the other containing Double White Killarney roses were used. A single bench in the White Killarney house was divided into four blocks with twelve plots of twenty plants each per block. The twelve treatments listed in table 6 were randomized in each block. In the Talisman house one-half of each of two benches was used and each half was divided into two blocks. The same twelve treatments were likewise randomized within each of the four blocks in plots of sixteen plants each. Thus, there were eight randomized replications of each treatment, four on each of two varieties of roses. At the beginning of the experiment very little mildew was present in any of the plots, but at the end of the five-week period the infection was very heavy in the check plots. The spray applications were made with a power sprayer at a pressure of 125 pounds per square inch. The spray mixtures were applied at the rate of approximately one gallon per twelve plants for each application. The dust was applied with a hand duster. No record was kept of the amount of dust applied; however, the foliage was thoroughly covered. Four applications of each material were made at weekly intervals, and the number of mildew lesions per plot was determined five days after the last application. The data were analyzed statistically by the analysis-of-variance method, and are summarized in table 6.

These results demonstrate the marked superiority of all of the spray materials tested in comparison with the sulfur dust. Even the wetting agent when used alone was more effective than sulfur dust. Also, the dust was the only material that caused any appreciable foliage discoloration. Another outstanding point shown by these data is that when regular spray applications are begun before the mildew becomes established, the disease can easily be controlled by protective spraying.

On the other hand, once the plants become severely infected with mildew, it is difficult to reduce the infection. The data presented in table 7 show this clearly. These data were obtained in a house of Talisman roses severely infected with mildew. The twelve plots of twenty-four plants each were randomized in each of four blocks on one bench. Two applications were made six days apart, and the percentage of lesions still actively

TABLE 6. EFFECTIVENESS OF SULFUR AND COPPER FUNGICIDES WHEN USED IN A PROTECTIVE-SPRAY PROGRAM FOR THE CONTROL OF MILDEW

Materials and concentrations*	Average number of lesions on 8 plants		
	White Killarney	Talisman	Average†
1. Walcolized Sulphur 1:1200 plus IN438 1:1000	4.8	7.8	6.3
2. Walcolized Sulphur 1:2400 plus IN438 1:1000	14.5	8.0	11.3
3. Walcolized Sulphur 1:4800 plus IN438 1:1000	18.0	14.0	16.0
4. Fungisul 1:2400 plus IN438 1:1000	13.8	10.0	11.9
5. "Mike" Wettable Sulfur 1:2400 plus IN438 1:1000	13.5	7.8	10.6
6. Green Kolodust	230.3	119.8	187.5
7. Flotation sulfur 1:2400 plus IN438 1:1000	46.3	5.3	25.8
8. Protex Colloidal Sulphur 1:2400 plus IN438 1:1000	17.3	8.5	12.9
9. Cuprocide 54 1:1600 plus IN438 1:1000	35.3	21.8	28.5
10. Cuprocide 54 1:3200 plus IN438 1:1000	41.3	17.3	29.3
11. IN438 1:1000	67.3	43.3	55.3
12. Check, unsprayed	427.0	213.3	320.1

*Sulfurs are here compared on the basis of their actual sulfur content and the concentrations are expressed in terms of actual sulfur content.

†The least difference necessary for significance with odds of 19:1 is 79.6, and for odds of 99:1 is 107.2.

TABLE 7. CONTROL OF MILDEW OBTAINED BY SPRAYING AND DUSTING HEAVILY MILDEWED TALISMAN ROSES WITH TWO APPLICATIONS OF DIFFERENT SPRAY MIXTURES

Material and concentration	Per cent of lesions active*
1. Ko-Sul 1:1200 plus IN438 1:1000	40.3
2. Ko-Sul 1:2400 plus IN438 1:1000	46.7
3. "Mike" Wettable Sulfur 1:600 plus IN438 1:1000	37.6
4. "Mike" Wettable Sulfur 1:1200 plus IN438 1:1000	63.0
5. Malachite green 1:10,000 plus IN438 1:1000	18.8
6. Malachite green 1:20,000 plus IN438 1:1000	22.8
7. Cuprocide 54 1:1600 plus IN438 1:1000	64.7
8. Cuprocide 54 1:3200 plus IN438 1:1000	65.6
9. Shirlan D 1:500	42.3
10. R. S. 380 1:400	20.8
11. Pomo-Green dust	93.1
12. Check, unsprayed	93.4

*Least difference necessary for significance with odds of 19:1 is 14.6, and for odds of 99:1 is 19.6.

sporulating was determined by observation five days after the second application. The data were analyzed statistically by the analysis-of-variance method. The applications were made during cloudy weather, and the temperature in the house averaged about 72°F. No discoloration was observed on any of the plants except from the malachite green; here the only discoloration was on the outer petals of buds which had opened sufficiently for the petals to show color. No injury occurred in any of the plots.

Again sulfur dust was not effective. Cuprocide 54 at the concentrations used was only slightly effective, which would be expected on the basis of the results of the laboratory tests summarized in table 5. The control obtained with "Mike" Wettable Sulfur at a concentration of 1:1200 was about the same as that obtained when the Cuprocide 54 was used, while

a concentration of 1 : 600 was much more effective. Of the materials used in this test, R. S. 380 and malachite green were the most effective.

In three different experiments a number of miscellaneous spray materials were compared for the eradication of mildew. The data from these tests are summarized in table 8. In each experiment two applications were made five days apart, and counts to determine the percentage of lesions still actively sporulating were made five or six days after the second application. All of the applications were made while the sun was shining brightly and the temperature of the greenhouses was averaging 90° to 95°F. Two benches of heavily mildewed rose plants of the variety Rome Glory were used in tests A and B. One bench of heavily infected plants of the Talisman variety were used in test C.

TABLE 8. COMPARISON OF MISCELLANEOUS SPRAY MATERIALS FOR THE ERADICATION OF POWDERY MILDEW IN COMMERCIAL GREENHOUSES

Test	Spray material and concentration	Percentage of lesions active			
		Average of contiguous checks*	Treated	Difference	Injury
A	1. Ko-Sul 1:1200 plus IN438 1:1000	85.6	10.8	74.8	None
	2. Ko-Sul 1:1200 plus S. E. C. Oil 1:800	80.2	30.1	50.1	None
	3. Cuprocide 54 1:3200 plus S. E. C. Oil 1:800	76.6	43.4	33.2	None
	4. Malachite green 1:5000 plus IN438 1:1000	76.4	7.6	68.8	None
	5. Potassium sulfide 1:270 plus IN438 1:1000	81.9	6.3	75.6	Moderate to severe
	6. Helione Yellow 1:4000 plus IN438 1:1000	85.2	16.5	68.7	Moderate
	7. S. E. C. Oil 1:800	86.6	83.4	3.2	None
	8. IN438 1:1000	87.5	88.8	−1.3	None
B	1. Sulfocide 1:200 plus IN438 1:1000	89.4	0.2	89.2	Severe
	2. Crystal Mildew Spray 1:100 plus IN438 1:1000	94.1	0.8	93.3	Severe
	3. Rosin mixture 1:200	96.9	81.3	15.6	None
	4. Lime-sulfur 1:100 plus rosin mixture 1:200	96.1	0.0	96.1	Very severe
	5. R. S. 380 1:400	96.1	1.7	94.4	None
	6. Ko-Sul 1:1200 plus IN438 1:1000	94.2	1.5	92.7	None
	7. IN438 1:1000	91.7	69.5	22.2	None
C	1. Palustrex Sulfonate-B 1:200	...	5.6†	...	None
	2. Nursery Volck 1:500	...	73.0	...	None
	3. Ortho Mildew Spray 1:33 ⅓	...	11.3	...	Very severe
	4. Organic Fungicide No. 20 1:267	...	18.0	...	None
	5. Phenothiazine 1:200 plus IN438 1:1000	...	8.8	...	None
	6. Ko-Sul 1:1200 plus IN438 1:1000	...	5.3	...	None
	7. Check, sprayed with water	...	93.5	...	None

*Each treatment in tests A and B had a corresponding check, or unsprayed, plot on each side, and each figure presented in this column represents the average percentage of lesions remaining active in the two contiguous check plots.

†Least difference necessary for odds of 19:1 in test C is 5.4, and for odds of 99:1, 7.4.

In test A the benches were divided into plots of seventy-two plants each, with an unsprayed check plot on both sides of each sprayed plot. Thus, each treated plot had two contiguous unsprayed check plots. In recording the results, the percentage of active lesions of an approximate total of 800 counted per plot was obtained. The average of the two contiguous check plots was determined for each treated plot. The difference between this and the percentage of active lesions in the treated plot serves as a basis for the comparison of the various materials. This difference should not be emphasized because the method of comparison admittedly is not the best. It is suitable for showing which of the fungicides are most effective, however.

The plots in test B were just one-half as large as those in test A, since at the conclusion of test A each check plot was divided into two equal plots of thirty-six plants each. One-half was sprayed, and the other half was left unsprayed as the check plot. The treatments in test C were replicated four times in plots of twenty-eight plants each, and the data were analyzed statistically by the analysis-of-variance method.

All of the sulfur-containing materials were extremely toxic to the mildew in these tests except Ko-Sul combined with S.E.C. Oil. In this test the wetting of the foliage, of the mildew hyphae, and of the spores was very poor. This factor is discussed later. Moderate to severe burning of the foliage occurred every time a soluble sulfur was applied under the conditions of high temperature and bright sun which prevailed during these tests. For this reason, the safer particulate sulfurs are preferred to the soluble sulfurs.

The concentration of malachite green employed in this experiment was too great, and caused severe foliage and blossom discoloration, but no injury. Palustrex Sulfonate-B was unsatisfactory because of its gumming effect on the spray equipment. Organic Fungicide No. 20 left an unsightly residue on the foliage. Phenothiazine gave satisfactory control but was very difficult to keep in suspension in the spray tank in spite of vigorous agitation.

Therefore, of the materials listed in table 8, only R.S. 380 and Ko-Sul were given further consideration for use in the control of powdery mildew of roses.

The control obtained by two applications of Ko-Sul, as shown in table 8, was much greater than that obtained in the test recorded in table 7. This difference was undoubtedly due to the fact that in the former instance the applications were made during a period of high temperature when the sulfur was more effective, while in the latter one the applications were made during normal winter greenhouse temperatures (68° to 72°F.).

USE OF WETTING AGENTS IN FUNGICIDES FOR THE CONTROL OF POWDERY MILDEW OF ROSES

The hyphae, conidiophores, and conidia of *Sphaerotheca pannosa* var. *rosae* are external to the suscept tissue except for the haustoria which penetrate into the epidermal cells. Also, the hyphae, conidiophores, and conidia are waxy, which makes it difficult to wet the fungus. This latter is also true of young rose foliage. Eyre and Salmon (1916) observed that to obtain the full fungicidal effect of ammonium-polysulfide solutions on the hop powdery mildew, it was necessary to add an auxiliary substance, such as soft soap, to facilitate the wetting of the conidiophores by the spray. These observations suggested the possible use of wetting agents as spray supplements to increase the effectiveness of fungicides for the control of rose mildew.

Entomologists have investigated the use of wetting and spreading agents in contact insecticides and have met with considerable success. Wilcoxon and Hartzell (1931) observed that, in spite of their high toxicity, nicotine solutions failed to give satisfactory kills of the tomato worm (*Phlegethontius quinquemaculata*) unless a spreading agent was used. They showed that the toxicity of nicotine solutions to *Aphis rumicis* followed

the same order as did the spreading coefficient (a factor obtained from the surface tension and the contact angle of the liquid used) when nicotine solutions containing either no spreader, calcium caseinate, Penetrol, or sodium oleate were compared. Ebeling (1939) showed the percentage of mortality of the California red scale, *Aonidiella aurantii,* to be correlated with the concentration of the spreading agent used; and Greenslade (1935) found the effectiveness of a nicotine spray for use against the woolly aphid, *Eriosoma lanigerum* Hausm., to be so closely correlated with spreading ability that he used the percentage of kill as a criterion of spreading power. The increased kill of the red scale and of the woolly aphid may be attributed to a greater penetration of the aqueous solutions between the waxy threads under the body of the red scale, and between those covering the body of the woolly aphid. These waxy threads may be analogous to the waxy hyphae of *Sphaerotheca pannosa* var. *rosae.*

CONTACT ANGLES ON THE SURFACE OF ROSE LEAVES

Comparison with surface-tension measurements. To compare the wetting and spreading properties of various materials on a solid surface, a reliable criterion for these properties must be used. That surface tension alone is not a reliable criterion for the degree of wetting expected has been pointed out by Robinson (1925), by O'Kane, et al. (1930), and by Ballard (1933). Data supporting this are presented in table 9. The surface tensions of the solutions were determined by measuring the height to which the different materials rose in a capillary tube having a diameter of 0.0107 centimeter and applying the formula $T = \frac{hrdg}{2}$, where T is the surface tension in dynes per centimeter, h is the height in centimeters of the column in the tube, r is the radius of the capillary in centimeters, d is the density in grams per centimeter squared of the solution (assumed to be 1 in each case), and g is the force of gravity taken as 980 dynes per centimeter. In general, there is fairly good correlation between the surface tension and the angle of contact formed when a drop of the solution is placed on a flat surface. This is referred to as the *contact angle* (figure 1). However, a 1 : 1000 solution of IN 181 has a lower surface tension than a 1 : 1000

TABLE 9. COMPARISON OF THE SURFACE TENSIONS OF VARIOUS SPRAY SUPPLEMENTS WITH THEIR CONTACT ANGLES ON HOLLYWOOD ROSE LEAFLETS SIX DAYS OLD

Material	Contact angle		Surface tension, dynes per centimeter
	Upper surface	Lower surface	
Water	102.4	122.9	72.4
Vatsol OT 1:1000	33.4	40.8	40.3
S. E. C. Oil 1:1000	56.2	66.3	...
Aresket 240 1:1000	61.4	83.1	69.2
Vatsol OS 1:1000	75.1	94.3	66.5
Santomerse S 1:1000	80.0	97.1	69.9
IN 181 1:1000	54.9	82.2	32.5
IN 438 1:500	64.3	...	43.8
IN 438 1:1000	67.4	85.7	55.0
IN 438 1:2000	72.8	...	66.0
IN 438 1:4000	78.0	...	68.6

solution of Vatsol OT, yet the magnitude of the contact angle of the latter material is much smaller than that of the former. Also, contact-angle measurements of 1:1000 solutions of Aresket 240 and of IN 438 agree rather closely but the difference in surface tension is relatively large.

Ebeling (1939), O'Kane et al. (1930), and Martin (1940 a) pointed out that both wetting and spreading are functions of the contact angle. The smaller the contact angle, the better the material wets and spreads. Evans and Martin (1935) correlated in a preliminary way the surface tension, area of spread, contact angles, and spray retention, and concluded that, although on the basis of each of these criteria it is possible to arrange various spray supplements in approximately the same general order of activity, the determination of any one characteristic is insufficient to give a general assessment of wetting and spreading properties. Ebeling (1939) acknowledged that the static contact angle may not be the true index of the wetting and spreading properties of a liquid, which occur "under the dynamic conditions existing when a spray is being applied". However, the contact angle of a liquid on the surface of a leaf seems to be the best single criterion now available for obtaining an indication of the spreading and wetting qualities of that liquid when it is deposited on that leaf.

Method of measuring contact angles. The measurements reported here are those of the advancing contact angle (Ebeling, 1939), and the methods used for making these measurements are modifications of those used by O'Kane and his associates (1930) and of those used by Ebeling. O'Kane and his associates (1930) photographed drops of spray liquid in contact with the integument of insects, plant surfaces (O'Kane, et al., 1937) and several artificial surfaces. These photographs were projected on a screen, thus enlarging the image of the drops about 150 times the diameter of the original drop. The contact angle was then determined by drawing a tangent to the point of contact of the liquid and the solid and measuring the angle made with the solid by the tangent. Ebeling simplified this procedure by projecting the image of the drop to a horizontal surface and then tracing the image on coordinate paper when the drop had come to rest. Then, by determining the greatest height of the drop (h) and the radius (x) of the base of the segments and substituting these in Mack's (1936) formula, $\theta = 2 \tan^{-1} \left(\frac{h}{x}\right)$, for the contact angle of a drop whose outline is a sphere, the contact angle was calculated.

For the contact-angle measurements reported in this paper, an apparatus was designed to project the images of the drops onto a small horizontal screen. The image was magnified about twenty times. It is believed that the method used was sufficiently accurate for the purposes for which it was designed. The light source was a Bausch and Lomb Research Microscope Lamp (No. 1815) and the lens used for the magnification of the drop was a 2.3 X objective. The leaves were pasted on glass slides which were placed on a cork. This served as a platform and was held in place between the light source and the objective by an adjustable clamp which was connected with the vertical rod of a ringstand. The image was projected into an opening in a box about 30 inches away from the objective. Inside the box was a mirror at a 45-degree angle; this

TABLE 10. CONTACT ANGLES OF SPRAY SUPPLEMENTS ON THE UPPER AND LOWER SURFACES OF HOLLYWOOD AND RAMBLER ROSE LEAVES (THE SMALLER THE ANGLE THE BETTER THE WETTING)

Number	Wetting agent	Concentration	Contact angles, in degrees			
			Rambler		Hollywood	
			Lower surface	Upper surface	Lower surface	Upper surface
1	Areskap 50	1:1000	46.0	44.0	...	...
2	Aresket 240	1:1000	40.6	45.3	83.1	61.4
3	Aresklene 375	1:1200	22.7	27.0	61.8	61.3
4	Aresklene 400	1:1200	30.3	35.3	59.4	61.0
5	Dreft	1:400	42.0	30.3	73.2	66.6
6	Goulac	1:400	74.8	64.6	...	...
7	Bindarene flour	1:400	80.4	65.6	...	...
8	Grasselli Spreader Sticker	1:1000	49.5	44.1	...	...
9	Gum arabic	1:500	70.9	59.1	...	...
10	IN 181	1:1000	...	...	82.2	54.9
11	IN 181 P	1:4300	5.0	14.4	102.8	90.3
12	IN 438	1:2000	13.6	23.2	83.1	72.3
13	Lethane Spreader	1:500	42.3	43.8	...	...
14	Morpholine oleate	1:500	...	...	29.2	33.3
15	Moytol	1:100	29.9	63.1	...	...
16	Nopoco Fish Oil	1:750	33.5	27.6	55.7	67.6
17	Nopoco Monosulphate	1:750	50.3	49.8	...	...
18	Nopoco 1288	1:750	60.4	43.6	...	...
19	Ox bile	1:1000	44.7	37.1	...	...
20	Penetrol	1:500	61.8	45.8	...	...
21	Potassium fish-oil soap	1:750	58.0	50.3	...	...
22	Pyrolene M. P.	1:1000	...	...	68.9	64.2
23	Rosin mixture	1:1000	49.1	50.1	88.1	93.5
24	Santomerse D	1:500	...	...	63.2	57.4
25	Santomerse S	1:1000	...	...	97.1	80.0
26	S. E. C. Oil	1:800	...	...	72.2	72.3
27	Sodium abietate	1:3200	85.1	59.0	...	...
28	Sodium oleate	1:1000	...	...	23.8	34.2
29	Soybean oil	1:500	74.9	61.4	...	...
30	SS_8	1:1000	59.4	75.1	...	...
31	SS_9	1:1000	65.1	95.8	...	...
32	SS_{10}	1:1000	89.8	62.1	...	...
33	Stantex Wetter No. 20	1:1000	...	...	97.9	82.8
34	Tergitol 7	1:400	...	...	26.5	31.4
35	Triethanolamine oleate	1:800	...	...	37.3	48.4
36	Ultrawet	1:400	...	...	71.5	53.6
37	Vatsol OS	1:500	50.7	43.9	94.3	75.1
38	Vatsol OT	1:1000	5.0	14.9	32.5	39.0
39	Vatsol OTC	1:500	37.8	37.2	...	...
40	Water	.....	77.6	58.7	122.9	102.4

reflected the image through an opening at the top of the box on which there was a thin plate of glass with a sheet of onionskin paper underneath to give a ground-glass effect. The contact angles were measured directly from the image by means of a transparent celluloid protractor provided with a movable arm. This arm could be moved around until it was tangential to the image of the drop at the point of contact, the contact angle being the angle inside the liquid (figure 1).

All of the contact-angle measurements reported herein have been made of drops on portions of rose leaves. Young, healthy rose leaflets were selected and cut into portions about 5 millimeters in diameter. Thus, several portions could be obtained from the same leaf, and comparisons of different materials could be made on different portions of the same leaf. Microscope slides were cut into halves lengthwise. The slide to be used was placed on the cork platform after the leaf portion had been fastened to the slide with rubber cement. A drop 3.5 to 4.0 millimeters in diameter was applied by touching a small-bore pipette filled with the

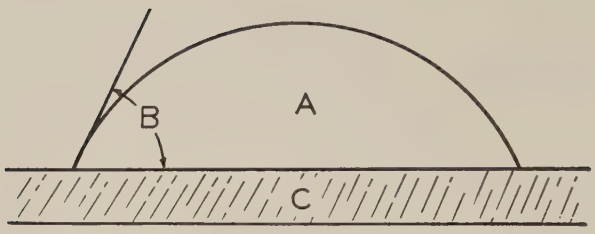

FIGURE 1. SIDE VIEW OF A DROP OF LIQUID (A) ON A LEAF SURFACE (C), SHOWING THE CONTACT ANGLE MEASURED (B)

liquid to the leaf surface. The size of the drop was not accurately controlled since it has been shown that significant differences in contact-angle measurements do not occur between drops varying between 1 and 5 millimeters in diameter (Ebeling, 1939). Two minutes were allowed to elapse before the measurements were made in order to permit the drop to come to equilibrium on the leaf surface.

Photographs of the images of six typical drops on rose leaves are shown in figure 2. It can readily be seen from these photographs that the smaller

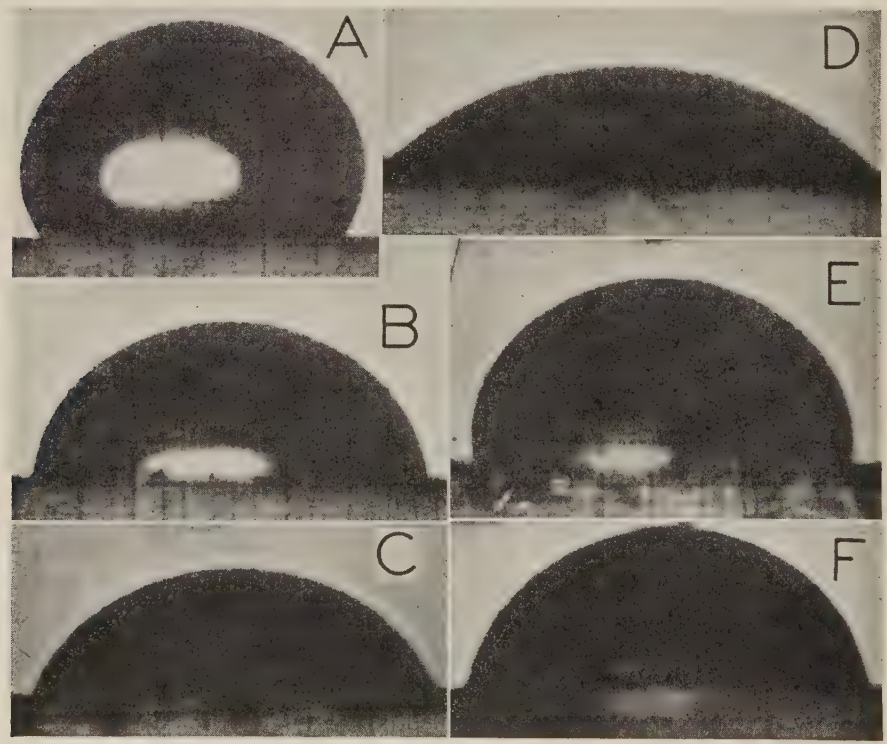

FIGURE 2. PHOTOGRAPHS OF THE PROJECTED IMAGES OF SIX TYPICAL DROPS ON ROSE LEAVES

A, B, and C are three different materials on six-day-old leaves of the variety Better Times (A, distilled water; B, IN438 1: 1000; and C, Vatsol OT 1: 1000). D and E are Vatsol OT 1: 1000 and distilled water, respectively, on six-day-old leaves of the variety Talisman. F is IN438 1: 1000 on the variety Hollywood.

the angle the better the material spreads. Sixteen angles were measured on the upper surface of portions of leaves. Similarly, sixteen angles were measured on the lower surface of the leaves, and the average was determined. Each angle reported in this paper is an average of sixteen measurements.

Contact angles of some spray supplements. The contact angles of thirty-nine different materials determined on outdoor-grown Rambler Rose leaves (probably Dorothy Perkins) and on indoor-grown leaves of the variety, Hollywood, are summarized in table 10. The concentrations used for these tests were those which have been recommended by the manufacturers or which have appeared in the literature. These data show that the Rambler Rose leaves were more easily wet than were the Hollywood leaves. This may be partially explained by the fact that the Rambler leaves developed outdoors and were subjected to the driving summer rains while the Hollywood leaves developed in the greenhouse, where they were not subject to these rains. These rains may have washed off part of the waxy bloom from the surface of the Rambler leaves.

Effect of age and surface of leaf on contact-angle measurements. In general, the lower surface of rose leaves is more difficult to wet than the upper surface. Stellwaag (1924) showed this to be true for two varieties of apples and one variety of vine (Reisling). However, this depends upon the material used. A liquid that has a low contact angle on one variety or surface does not always have a low contact angle on all varieties or surfaces. For example, in the data presented in table 10 the contact angle of a solution of IN 438 is very small on the Rambler leaves and large on Hollywood leaves.

It has been shown by Stellwaag that the contact angle of a given liquid varies with the age of the leaf. This is further substantiated by the line graphs in figure 3. The variation in the contact angles of solutions of IN 438 and of Vatsol OT with the age and with the surface of the leaf is also shown. Data for these line graphs were obtained by the daily tagging and dating of rose leaves of the varieties Better Times and Talisman as they unfolded. These plants were growing under glass. At the end of fifty-one days the tagged and dated leaves were collected, and the magnitudes of the contact angles of Vatsol OT and of IN 438 were determined on portions of these leaves. The leaves of Better Times and of Talisman were "hard" when 26 days old; that is, they were tough and dark green. An interesting point shown by these graphs is that in every instance but one, the contact angles were less when the leaves were only one day old than when the leaves were slightly older. Possibly the waxy bloom had not yet formed on the leaves. The curves are rather irregular, probably because of fluctuations in the growth rate due to changing environmental conditions during the fifty-one-day period.

Effect of variety of roses on contact-angle measurements. Comparisons were made of the contact angles of water, IN 438, and Vatsol OT on the upper and on the lower surfaces of leaves four days old and of leaves nineteen days old of each of six different varieties: Better Times, Hollywood, Briarcliff, White Killarney, Queen Mary, and Talisman. The data appear in table 11. No differences in the magnitude of the contact angles are apparent between the leaves of the two age groups, nor are any striking

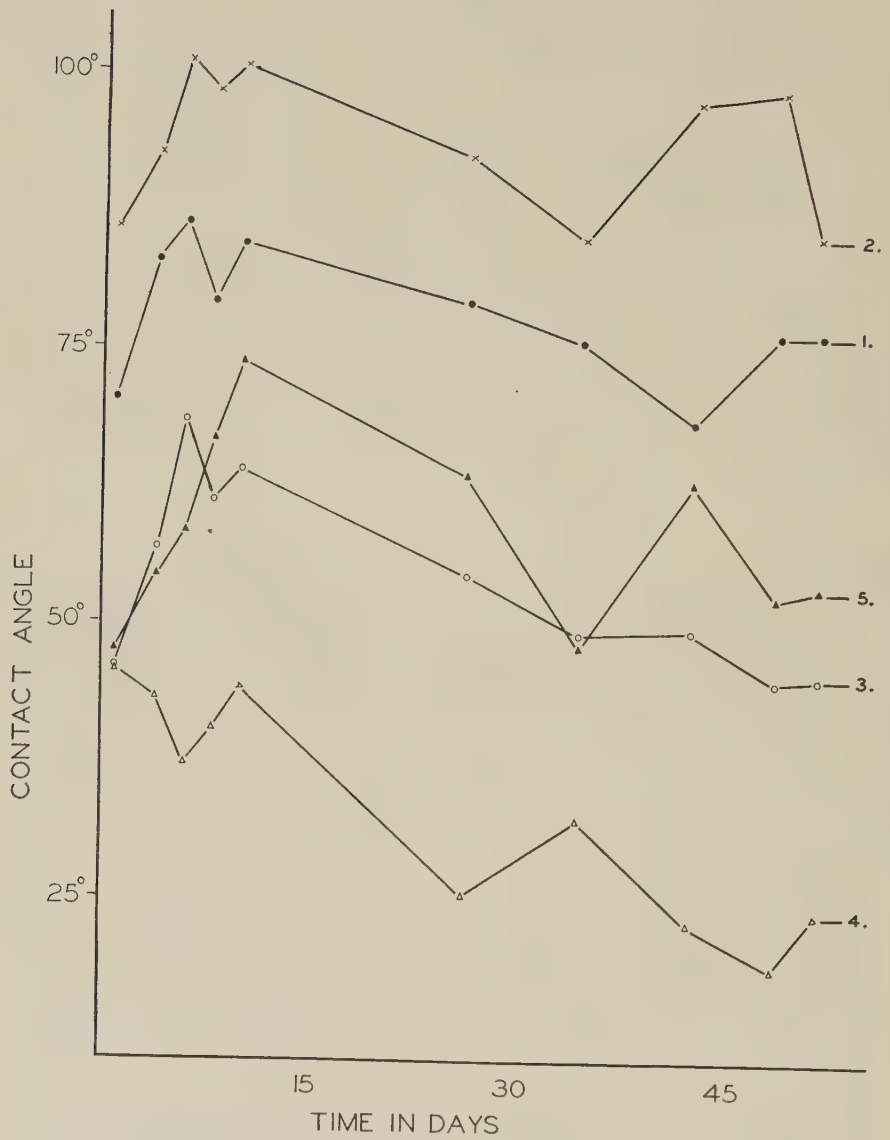

FIGURE 3. EFFECT OF THE AGE AND THE SURFACE OF THE LEAF ON CONTACT-ANGLE MEASUREMENTS

1, 2, and 3 represent measurements on leaves of the variety Better Times. 1 represents IN438 1: 1000 on the upper leaf surface, and 2 is the same material on the lower leaf surface. 3 is Vatsol OT 1: 1000 on the upper leaf surface, and 4 and 5 are measurements of the contact angles of Vatsol OT 1: 1000 on the upper and on the lower leaf surfaces, respectively, of the variety Talisman.

differences apparent between the varieties, although the contact angles are slightly lower on the upper surface of the Talisman leaflets.

TOXICITY OF WETTING AGENTS

The toxicity of the different wetting agents, which were employed in greenhouse tests, to the conidia of *Sphaerotheca pannosa* var. *rosae* has been determined in the laboratory by using the spore-germination technique as described on page 4. Rather significant data were obtained from

TABLE 11. EFFECT OF VARIETY ON CONTACT ANGLE MEASUREMENTS, AT TWO DIFFERENT AGES AND ON UPPER AND LOWER SURFACES

Variety	Contact angles on rose leaves					
	Upper surface					
	Leaves 4 days old			Leaves 19 days old		
	Water	IN 438	Vatsol OT	Water	IN 438	Vatsol OT
Better Times	100.3	74.8	51.4	104.5	82.8	45.6
Hollywood	89.9	86.7	56.9	105.4	78.5	50.9
Briarcliff	94.9	76.5	40.6	100.2	86.9	44.2
White Killarney	100.8	83.1	36.8	95.1	73.5	41.7
Queen Mary	103.6	84.8	37.9	103.0	81.6	43.3
Talisman	84.6	61.8	31.0	91.8	61.5	31.6
	Lower surface					
Better Times	115.4	81.2	47.5	104.2	89.1	53.3
Hollywood	104.9	89.2	56.5	108.3	92.4	49.1
Briarcliff	112.5	91.3	37.4	109.6	91.8	31.4
White Killarney	115.4	103.0	36.4	112.8	96.6	44.4
Queen Mary	114.4	93.5	37.0	116.2	97.6	46.1
Talisman	102.8	87.2	38.8	112.1	95.4	32.1

these tests and are summarized in table 12. It is apparent that IN 181, Aresklene 375, rosin mixture, and Vatsol OT have a high degree of toxicity to the conidia of *Sphaerotheca pannosa* var. *rosae;* Aresket 240, S.E.C. Oil, gelatin, Nopoco Fish Oil, and Santomerse S are relatively non-toxic; while IN 438, IN 181P, Crystal Soap Spreader, sodium oleate, Grasselli Spreader Sticker, and Tergitol No. 7 are intermediate in their toxicity.

The toxicity of wetting agents that have been used rather extensively in spray solutions in tests under actual greenhouse conditions was tested further in the laboratory to compare these wetting agents as "eradicants" and as "protectants" by the method described on pages 9 and 10. The data are presented in table 13 and show that the toxicity of IN 438 and Aresket 240 when employed as "eradicants" was greater than the toxicity exhibited when they were used as "protectants". There was little or no difference in the toxicity of the other materials when used either as a "protectant" or as an "eradicant".

These data present evidence that certain wetting agents, such as IN 181, IN 438, and Vatsol OT, possess considerable inherent toxicity. The factor of the toxicity of spray supplements should be considered when fungicides containing different spray supplements are compared.

TABLE 12. TOXICITY OF FIFTEEN SPRAY SUPPLEMENTS TO THE CONIDIA OF *Sphaerotheca pannosa* VAR. *rosae* AS MEASURED BY SPORE GERMINATION

Wetting agent	Concentration	Number of replications	Wetting agent		Checks		Per cent germination in relation to the respective check
			Number of spores	Per cent germination	Number of spores	Per cent germination	
Aresket 240	1:1000	3	1,292	43.2	1,487	61.3	70.5
Aresklene 375	1:1000	1	177	18.1	449	65.3	27.7
Crystal Soap Spreader	1:128	3	1,000	44.1	782	66.6	66.2
Gelatin	1:333	3	1,017	62.3	1,147	73.9	84.4
Grasselli Spreader Sticker	1:1000	1	430	38.7	744	62.0	62.3
IN 181	1:1000	2	630	7.3	893	79.5	9.2
IN 181 P	1:1000	1	383	38.7	578	71.3	54.3
IN 438	1:1000	3	1,250	42.8	1,471	86.8	49.4
Nopoco Fish Oil	1:750	1	321	66.4	433	79.8	83.2
Rosin mixture	1:100	1	265	14.3	433	79.8	17.9
Santomerse S	1:1000	2	892	50.3	942	67.1	74.9
S. E. C. Oil	1:800	3	1,430	51.2	1,279	63.8	80.4
Sodium oleate	1:1000	1	356	36.8	430	53.0	69.4
Tergitol No. 7	1:400	1	306	42.7	578	71.3	59.9
Vatsol OT	1:1000	4	1,365	19.6	1,537	77.8	25.2

TABLE 13. EFFECT OF SIX LIQUID AND DRY SPRAY SUPPLEMENTS ON GERMINATION OF CONIDIA OF *Sphaerotheca pannosa* VAR. *rosae* ON EXCISED ROSE LEAFLETS

Material (concentration, 1:1000)	Per cent germination		
	Check (unsprayed)	Protection (material was applied to leaflet and allowed to dry *before* conidia were dusted on leaflet)	Eradication* (material was applied to leaflet and allowed to dry *after* conidia had been dusted on leaflet)
IN 438	84.08	36.00	19.52
IN 181	79.51	7.30	4.33
Vatsol OT	84.59	21.48	27.97
S. E. C. Oil	69.26	54.67	52.59
Aresket 240	59.54	44.95	28.12
Santomerse S	67.09	50.00	46.19

*The conidia used in obtaining the data for this column were in contact with the liquid spray supplement before they germinated. Since the germ tubes had not penetrated into the leaf tissues at the time the conidia were in contact with the liquid, this cannot be considered to be true eradication.

COMPARISON OF WETTING AGENTS AS SPRAY SUPPLEMENTS FOR THE CONTROL OF ROSE MILDEW UNDER COMMERCIAL GREENHOUSE CONDITIONS

In the spring of 1939 an experiment was conducted to compare three wetting agents: IN 438, Aresket 240, and S.E.C. Oil, each at two concentration levels, 1 : 1000 and 1 : 2000, in combination with Ko-Sul 1 : 1200. The test was carried out in a house of Talisman roses which were heavily infected with mildew. Each treatment was replicated and randomized on each of three benches. Eleven applications were made at weekly intervals, and the final results were recorded six days after the last application. Counts were made of the number of mildew lesions on thirty young leaflets and also of the number of adults of the red spider on thirty-three leaflets taken at random in each plot. The data were treated statistically by the analysis-of-variance method, and are presented in table 14.

The probable reason for the lack of better control was the use of a

spray hose 260 feet long. Undoubtedly a considerable amount of sulfur settled in the spray line, even though the suspension was kept well agitated in the spray tank and a pressure of 375 pounds per square inch was used.

The most striking results of these tests were the obvious differences between the sprayed and the unsprayed plots. These differences were

TABLE 14. CONTROL OF POWDERY MILDEW AND RED SPIDERS ON TALISMAN ROSES, OBTAINED WHEN DIFFERENT WETTING AGENTS, EACH AT TWO CONCENTRATIONS, WERE USED IN COMBINATION WITH KO-SUL

Material and concentration	Average number of lesions on 30 leaflets*	Average number of adult red spiders on 33 leaflets
1. Ko-Sul 1:1200 plus IN 438 1:1000	37.7	79.3
2. Ko-Sul 1:1200 plus IN 438 1:2000	46.0	115.7
3. Ko-Sul 1:1200 plus Aresket 240 1:1000	63.7	95.0
4. Ko-Sul 1:1200 plus Aresket 240 1:2000	70.0	175.0
5. Ko-Sul 1:1200 plus S. E. C. Oil 1:1000	55.3	134.3
6. Ko-Sul 1:1200 plus S. E. C. Oil 1:2000	86.0	161.7
7. Ko-Sul 1:1200	86.7	132.7
8. Check, sprayed with water only	143.0	197.0
9. Check, not sprayed or syringed	301.0	254.7

*The least differences necessary for significance with odds of 19:1 are 125.0 lesions and 84.7 spiders, and for odds of 99:1, 168.4 lesions and 115.6 spiders, respectively.

apparent on casual observation, especially those between the plots of treatment 1 and treatments 8 and 9. Treatment 1 gave by far the best control. With but a few exceptions the plots could be rated, on the basis of appearance, in the same order in which they are listed in table 14. The improved appearance was due to the reduction in the number of red spiders and in the amount of mildew.

TABLE 15. CONTROL OF MILDEW AND RED SPIDERS ON TALISMAN ROSES, OBTAINED WITH KO-SUL AT A RATE OF 1:1200 AND WETTING AGENTS AT 1:1000 AND 1:2000

	IN 438		Aresket 240		S. E. C. Oil		Mean	
	Lesions	Spiders	Lesions	Spiders	Lesions	Spiders	Lesions	Spiders
	Number							
1:1000	37.7	79.3	63.7	95.0	55.3	134.3	52.2*	102.9
1:2000	46.0	115.7	70.0	175.0	86.0	161.7	67.3	150.8
Mean	41.7*	97.5	66.8	135.0	70.6	148.0	...	...

*The least difference necessary for significance between concentrations of wetting agents is 13.9 lesions for odds of 19:1 and 19.0 for odds of 99:1; for significance between different wetting agents the values are 18.1 and 23.5 lesions, respectively.

When the data for treatments 1 to 6 are analyzed statistically as a factorial design and when comparisons are made of the two concentrations, as well as of the three wetting agents, the differences between wetting agents and between concentrations of wetting agents are significant. The data appear in table 15. The control obtained when IN 438 was used was significantly better than that obtained when Aresket 240 or S.E.C. Oil was used. The differences between the two concentrations were significant; the higher concentration gave the better control. Such differences also

occurred in the number of red spiders present in the plots at the end of the experiment.

To further test the effect of these spray supplements when used in an eradicant-spray program, an experiment was conducted in the spring of 1940 in a house of Talisman roses heavily infected with mildew. Two benches were selected, and the twelve treatments listed in table 16 were randomized in each of four blocks. This provided four replications of each material in plots of twenty-four plants each. The plants were sprayed at a pressure of 125–150 pounds. Two applications were made six days apart, and the percentage of lesions still active was determined for each plot five days after the second application. Marked differences in control were obtained. The data were treated statistically by the analysis-of-variance method and entered in table 16 under the heading *Eradication.*

As stated above, the control of powdery mildew varied considerably with the use of different wetting agents (pages 22 and 23) when the plants sprayed were already infected with mildew. The question then arose as to whether similar results would be obtained if these same wetting agents were used as spray supplements on plants having little, if any, mildew infection at the beginning of the spray program. Accordingly, a house of roses of the variety Better Times was selected for such a comparison. There were four benches in this house, and the plots of the twelve treatments listed in table 16 were randomized on each of the benches, each plot having 24 plants. The materials were applied at a pressure of 125–150 pounds. Some spray drift was unavoidable on two of the four benches. This was strikingly apparent at the end of the experiment in the unsprayed check plots. There were 257 and 479 lesions per 24 plants, respectively, in the two check plots not affected by the spray drift, and 68 and 90 lesions per 24 plants, respectively, in the two check plots that received the spray drift. Four applications were made at weekly intervals, and

TABLE 16. CONTROL OF MILDEW ON THE BETTER TIMES VARIETY OF ROSE, OBTAINED WITH WALCOLIZED SULPHUR 1:1200 COMBINED WITH DIFFERENT SPRAY SUPPLEMENTS IN AN ERADICATIVE-SPRAY PROGRAM AND IN A PROTECTIVE-SPRAY PROGRAM

Spray supplement and concentration		Eradication* (mildew infection was very *heavy* at beginning of experiment. Two spray applications were made six days apart)	Protection* (mildew infection was very *light* at beginning of experiment. Four spray applications were made at weekly intervals)
		Per cent of lesions active	Average number of lesions on 24 plants
1. IN 438	1:500	12.8	4.1
2. IN 438	1:1000	16.7	6.3
3. IN 438	1:2000	40.3	5.3
4. IN 438	1:4000	58.9	11.3
5. Aresket 240	1:1000	37.1	4.0
6. S. E. C. Oil	1:1000	65.9	15.3
7. Santomerse S	1:1000	62.7	7.8
8. Vatsol OT	1:1000	4.5	3.3
9. IN 181	1:1000	20.3	8.8
10. Grasselli Spreader Sticker	1:1000	24.1	5.8
11. No wetting agent added	.....	87.1	83.0
12. Check, unsprayed	.....	97.2	223.5

*The least differences necessary for odds of 19:1 are 8.2 per cent and 81.5 lesions; and for odds of 99:1, 11.0 per cent and 109.4 lesions.

counts were made of the total number of lesions on the 24 plants in each plot five days after the last application. By this time a considerable amount of mildew had appeared in the check plots. The data, analyzed by the analysis-of-variance method, are presented in table 16 under the heading *Protection.*

It is apparent from the data presented in table 16 that a good wetting agent is needed if spraying is begun after the rose plants have become heavily infected with mildew. On the other hand, if spraying is begun when mildew first appears, one wetting agent seems to be about as efficient in controlling mildew as another. In fact, there were no statistical differences between any of the treatments containing wetting agents plus Walcolized Sulphur and those treatments in which Walcolized Sulphur was used alone, when these materials were used in a protective-spray program.

The control obtained when Vatsol OT plus Walcolized Sulphur was used in the eradication-spray program was superior to that of all of the other materials tested. There were no statistical differences between the control obtained with IN 438, IN 181, and Grasselli Spreader Sticker when they were used at the same concentration. The control obtained when IN 438 was used as the spray supplement was in direct relation to its concentration; the best control was obtained with the highest concentration.

The question now arises as to the manner in which these wetting agents, when used as spray supplements, increase the efficiency of a given toxicant (sulfur, in this case). As has been shown, when some of these supplements are used in spray mixtures, the rose foliage is much more easily wet; other supplements are decidedly toxic to the conidia of *Sphaerotheca pannosa* var. *rosae;* and one, Vatsol OT, is extremely toxic and wets the rose foliage very well. In an attempt to correlate the differences in control resulting from the use of these various supplements, data from spray tests in greenhouses have been compared with laboratory tests and are summarized in table 17. The thesis of the writer is that both of these properties, wetting and toxicity to *Sphaerotheca pannosa* var. *rosae,* increase the effectiveness of spray materials for the control of mildew, but that wetting may be dominant in one instance, whereas in another the toxicity of the wetting agent may be more important. In some instances these two properties may assume approximately equal importance. For example, Walcolized Sulphur plus Vatsol OT was far more efficient than any of the other materials tested under greenhouse conditions. Laboratory tests have shown that this material wets the foliage much better than do any of the other materials, and that it is more toxic than any other material tested except IN 181. Therefore, when using Vatsol OT, toxicity and wetting may be of approximately equal importance. Also, the better wetting property of Vatsol OT offsets the higher toxicity of IN 181, and is therefore more efficient in sprays for controlling mildew. The contact angles of IN 438 and of Aresket 240, each at a concentration of 1 : 1000, are approximately the same, but IN 438 is considerably more toxic than Aresket 240 and is therefore a better spray supplement, as shown by the increased control obtained when it is used.

TABLE 17. SUMMARY OF THE RESULTS OF LABORATORY AND GREENHOUSE TESTS WITH WETTING AGENTS

Material and concentration	Greenhouse spray tests		Laboratory tests (sulfur was not used with the spray supplements in these tests)		
	Protection* (mildew infection was very *light* at beginning of experiment; four spray applications at weekly intervals)	Eradication* (mildew infection was very *heavy* at beginning of experiment; two spray applications six days apart)	Contact angles on Holly-wood rose leaves (upper surface)	Per cent spore germination in relation to checks	
	Average number of lesions on 24 plants	Per cent of lesions active		Protection (material was applied and allowed to dry *before* conidia were dusted on leaflet)	Eradication (material was applied and allowed to dry *after* conidia had been dusted on leaflet)
1. Walcolized Sulphur 1:1200 plus IN 438 1:500	4.1	12.8	64.3	...	...
2. Walcolized Sulphur 1:1200 plus IN 438 1:1000	6.3	16.7	67.4	42.8	23.2
3. Walcolized Sulphur 1:1200 plus IN 438 1:2000	5.3	40.3	72.8	...	...
4. Walcolized Sulphur 1:1200 plus IN 438 1:4000	11.3	58.9	78.0	...	...
5. Walcolized Sulphur 1:1200 plus Aresket 240 1:1000	4.0	37.1	61.4	75.6	47.2
6. Walcolized Sulphur 1:1200 plus S. E. C. Oil 1:1000	15.3	65.9	56.2	78.9	76.0
7. Walcolized Sulphur 1:1200 plus Santomerse S 1:1000	7.8	62.7	80.0	74.5	68.8
8. Walcolized Sulphur 1:1200 plus Vatsol OT 1:1000	3.3	4.5	33.4	25.4	33.1
9. Walcolized Sulphur 1:1200 plus IN 181 1:1000	8.8	20.3	54.9	9.2	5.4
10. Walcolized Sulphur 1:1200 plus Grasselli Spreader Sticker 1:1000	5.8	24.1	...	...	...
11. Walcolized Sulphur 1:1200	83.0	87.1	102.4	96.4	100.0
12. Check, not sprayed	223.5	97.2	...	...	...

*The least differences necessary for odds of 19:1 are 81.5 lesions and 8.2 per cent; and for odds of 99:1, 109.4 lesions and 11.0 per cent.

SULFUR VAPORIZATION

The painting of steam or hot-water pipes with sulfur has long been advocated for the control of powdery mildew of roses and is a general practice among operators who grow roses commercially. Bergmann[4] first introduced the method of painting hot water pipes with sulfur. Others, including Maynard (1890) and Norton and White (1911), have also recommended the vaporization of sulfur for the control of rose mildew. More recently Bewley (1929) and Guba (1929, 1939) have recommended the vaporization of sulfur for the control of tomato leaf mold (*Cladosporium fulvum* Cke.). The recent tendency among commercial rose growers has been to maintain a lower steam pressure in their steam lines. Coupled with this tendency is the common observation that at the present time sulfur painted on the pipes is not always effective.

The vapor pressure of sulfur is approximately doubled with an increase in temperature of 10°C. (figure 4). Likewise, as steam pressure increases, temperature increases. Thus, by increasing the steam pressure in the pipes in a greenhouse, more sulfur vapor is evolved. This may help explain the poor mildew control obtained in many greenhouses. With the possibility in mind that control is poor when sulfur is vaporized at a low temperature, preliminary experiments were undertaken to study the relationship between the temperature at which sulfur is vaporized and the control of mildew.

A glass-enclosed chamber of 29.5 cubic feet capacity, with an opening at one end into which was fitted an L-shaped metal cylinder three inches in diameter, was used in these experiments. This cylinder was flanged at one end, and fitted loosely over an electric hot plate, the temperature of which was controlled by means of a variable resistance. An electric fan underneath the hot plate provided a gentle current of air, which moved upward around the hot plate and into the chamber. The temperature in the chamber was maintained at approximately 70°F. by means of a thermostat and two resistance coils.

In the actual operation of a given experiment two or more varieties of plants having a comparable amount of mildew were selected. One-half of the plants of each variety were put into the vaporization chamber, and the others were kept in a greenhouse maintained at 70° to 75°F. to serve as a check. Ten grams of ground elemental sulfur was placed on the surface of the hot plate, which was adjusted to the desired temperature. The plants were subjected to the sulfur vapor, which was carried into the chamber by the current of air, for three days, and were then removed from the chamber. Several young leaflets were taken from these and from the check plants for spore-germination tests. Both the treated and the check plants were placed in a moist chamber for twenty-four to forty-eight hours, after which the percentage of lesions still actively sporulating was determined. Fresh spores were dusted over the excised leaflets and the percentage of spore germination was determined after twenty-four hours. This gave a biological test for sulfur deposition. Five varieties of roses: Talisman, White Killarney, Queen Mary, Briarcliff, and Hollywood, were used in these tests.

The results of the tests are summarized in table 18. They show that

[4]The gardeners' chronicle and agricultural gazette, p. 419 [London], 1852.

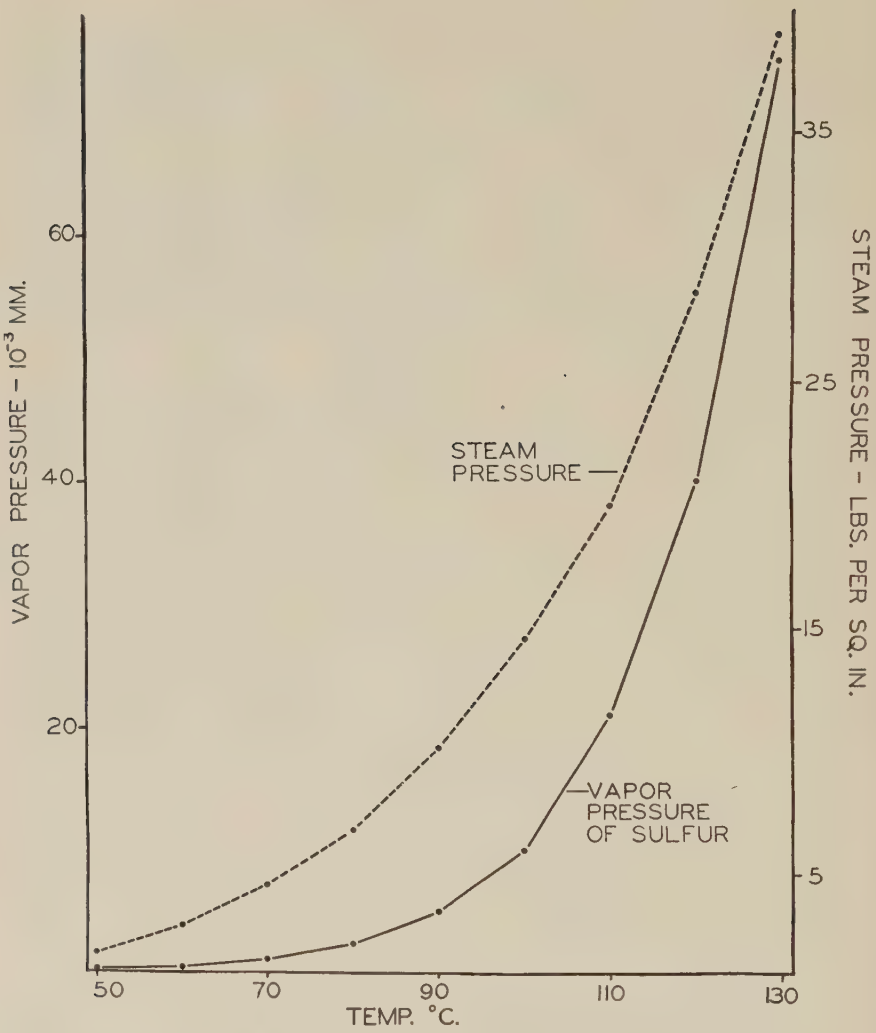

FIGURE 4. RELATIONSHIP BETWEEN STEAM PRESSURE AND TEMPERATURE AND BETWEEN TEMPERATURE AND THE VAPOR PRESSURE OF SULFUR

The steam-pressure curve is based on atmospheric pressure. To obtain the gauge pressure at any point on the curve, 14.697 pounds per square inch should be subtracted. Thus, at 100°C. the gauge pressure is zero instead of 14.697 pounds per square inch. [The data for these graphs were obtained from Hodgman (1939) and from Menzies (1928).]

the amount of sulfur deposited on the leaflets during the three-day interval was not enough to affect spore germination. Sulfur vaporized at a temperature of 112° to 115°C. killed the mildew in the majority of the lesions. This did not occur when sulfur was vaporized at a lower temperature (85°C.). This therapeutic action of vapors from sulfur compounds has been described by Yarwood (1940) for rusts and powdery mildews on other plants.

TABLE 18. EFFECT OF SULFUR VAPORIZED AT DIFFERENT TEMPERATURES ON THE ACTIVE LESIONS OF *Sphaerotheca pannosa* VAR. *rosae* AND ON SULFUR DEPOSITION AS MEASURED BY THE GERMINATION OF THE CONIDIA ON EXCISED ROSE LEAVES

Treatment	Number of varieties	Number of plants	Number of replications	Activity of lesions				Spore germination			
				Treated		Check		Treated		Check	
				Number counted	Per cent active	Number counted	Per cent active	Number counted	Per cent germination	Number counted	Per cent germination
Sulfur vaporized at 85° C	4	18	3	537	77.4	618	92.5	1,716	81.3	1,559	78.4
Sulfur vaporized at 112–115° C	3	22	3	600	6.8	891	83.5	3,005	62.0	2,861	58.8
No sulfur vaporized	3	6	1	181	61.9	186	70.5	632	81.7	628	76.7

These preliminary data would indicate that the present tendency toward a reduction in steam pressure is causing a decrease in the efficiency of the method of vaporizing sulfur on the heating pipes. Guba (1929), reporting on greenhouse tests with sulfur on the heating pipes for the control of tomato leaf mold, states, "In Massachusetts, varying results have been obtained in proportion to the area of pipe surface treated and the temperature of the pipes." The same statement may also be made in regard to the control of rose mildew. Further research may result in the development and the popular use of sulfur vaporizers such as those described by Guba (1929) and others (Rupprecht, 1932; Bewley, 1929), or it may result in the use of greater steam pressure to vaporize sulfur for practical mildew control.

SYRINGING FOR THE CONTROL OF MILDEW

Syringing for the control of the red spider is a general practice among growers of greenhouse roses. A number of greenhouse operators have observed that rose mildew also was checked by this syringing, and Yarwood (1939) reported marked control of this and other powdery mildews in a limited laboratory experiment. To further substantiate this, a test was conducted in a commercial rose house, using the variety Yellow Joanna Hill. A bench of severely mildewed plants was divided into 16 plots with four treatments randomized by the Latin Square method. The syringing was done with the ordinary type of syringing nozzle under a pressure of approximately one hundred pounds per square inch and was directed at both surfaces of the leaf. The experiment was carried on over a period of four weeks. The results are summarized in table 19. It can be seen that syringing definitely reduces the amount of mildew and that this reduction is proportional to the number of applications per week. However, the control obtained is not sufficient for practical purposes even on the plots where syringing was done daily, except Sunday, throughout the week.

TABLE 19. CONTROL OF POWDERY MILDEW ON THE VARIETY YELLOW JOANNA HILL, OBTAINED BY SYRINGING

Treatment number	Syringed on—	Average number of lesions on young leaflets of 8 plants 5 days after the last syringing*
1	Monday, Tuesday, Wednesday, Thursday, Friday, Saturday	112.50
2	Monday, Wednesday, Friday	292.25
3	Monday, Thursday	312.75
4	Monday	430.50

*The least difference necessary for odds of 19:1 is 135.5, and for odds of 99:1 is 205.0.

The author agrees with Yarwood's conclusion that the appearance of the treated plants is much better than that of the control plants. This is due to the reduction of the number of red spiders, as well as to the reduction in the amount of mildew in the treated plots. However, since syringing often provides ideal conditions for the dissemination of spores of *Diplocarpon rosae* causing blackspot, and since there is an increased amount of labor involved, the author would certainly hesitate to recommend this as a sound control practice.

DISCUSSION OF THE PRACTICAL APPLICATION OF THESE RESULTS FOR THE CONTROL OF MILDEW

Much of the information set forth here may well be put into practical use for the control of powdery mildew of roses. As Longrée (1939) has pointed out, this disease cannot be effectively controlled under greenhouse conditions through regulation of temperature and humidity. Therefore, the application of fungicides is indispensable in the control of the disease.

The data presented here demonstrate the ineffectiveness of sulfur dust for controlling the disease. On the other hand, the sulfurs, when used as sprays with a suitable wetting agent, were extremely effective. Particulate sulfurs are preferable to soluble sulfurs because of the frequent and serious burning of the rose foliage caused by the soluble sulfurs, together with their harmful effect on photosynthesis (Hyre, 1939).

The coppers are poor protectants for powdery mildew of roses, as compared with sulfurs. However, soluble copper may be effective in eradicant sprays, while insoluble copper is not. Malachite green is very effective at the dilution of one part in 10,000 parts of water; but it discolors open blossoms. However, it may well be used to keep young plants free of mildew before they come into production, to destroy the mildew on plants that have been cut back, and to destroy mildew on varieties such as Talisman, the blossoms of which are cut just after they begin to show color.

One of the most important factors in the control of powdery mildew of roses is the timing of the spray applications. If spray applications are begun when mildew first appears, the disease may be controlled easily; but if the grower delays until the plants become heavily infected with mildew, he will find the disease extremely difficult to control. If the disease has progressed to this stage, it will be necessary for the grower to use an efficient wetting agent with the fungicide in his spray mixture. The wetting agent to be used should be toxic to the mildew and should possess excellent wetting properties. Of the materials tested, Vatsol OT is the best material to use as a spray supplement under these conditions because of its marked wetting ability and its toxicity to the mildew. However, owing to the high cost of this material, a cheaper supplement, such as Grasselli Spreader Sticker, might well be used.

Data on control of mildew by vaporizing sulfur from the heating pipes are not conclusive, but they strongly indicate the need for high temperatures for vaporization. Growers who use hot water for heating undoubtedly find that volatilizing sulfur from the pipes does not check mildew. Low steam pressures also are unsatisfactory. High steam pressures (fifteen pounds or more) or increased pressures when vaporizing sulfur may give effective mildew control. One grower near Buffalo, New York, reports no mildew control when he puts sulfur on heating pipes carrying a low steam pressure. However, he has installed a high-pressure line (85 pounds pressure at the boiler), which gives excellent mildew control with no foliage injury. Another grower in this same area makes a regular practice of vaporizing sulfur once a week in his houses. His steam lines have a pressure of 15 pounds at the boiler, and he finds that this weekly sulfur vaporization keeps his houses free from mildew except during the summer when he does not run steam. The need for further experi-

mental data on the use of volatile materials for the control of powdery mildew of roses is evident.

Control of powdery mildew of roses by syringing might be effective if the syringing is started before the pathogen becomes established. However, it would seem unwise to recommend such a practice even if it should give effective control, since ideal conditions would be provided for the development of blackspot.

SUMMARY

The use of fungicides for the control of powdery mildew of roses, caused by the pathogen *Sphaerotheca pannosa* (Wallr.) Lév. var. *rosae* Wor., under greenhouse conditions, was investigated both in the laboratory and under commercial greenhouse conditions.

The toxicity of fifty different fungicides to the conidia of *Sphaerotheca pannosa* var. *rosae* on excised rose leaves was determined by spore-germination tests. The marked superiority of the protective action of sulfur-containing materials over that of the copper-containing materials was clearly demonstrated in these tests. Of fourteen copper-containing materials, only three: ammoniacal copper carbonate, Palustrex Sulfonate-B, and Eau Céleste, reduced spore germination 75 per cent or more, whereas, of the sulfur-containing materials, a reduction of at least 75 per cent occurred in every test but the one in which Crystal Mildew Spray was used. Of twenty miscellaneous materials tested, four: Helione Green, Helione Yellow, malachite green, and Shirlan D, reduced germination 75 per cent or more.

A method was devised for the comparison of the toxicity of different fungicides to conidia on rose leaves. This involves the germination of spores from the same population on different portions of the same excised leaf. Each leaf is divided into six approximately equal portions, and a known amount of a given fungicide is applied to each portion by means of a spray tower. Conidia are then dusted over all of the leaf portions simultaneously. Small differences in toxicity were measured accurately, using this method, and the data obtained were analyzed statistically. The largest error in this method was the differences which occurred between spore populations obtained on successive days.

The toxic action of ten different materials, including a particulate sulfur, soluble and insoluble coppers, and silver, on the conidia of *Sphaerotheca pannosa* var. *rosae* on rose leaves was investigated. When conidia were not wet by the fungicidal mixture, only sulfur reduced spore germination appreciably; but when conidia were wet with these mixtures for a short time, the soluble coppers as well as sulfur markedly reduced spore germination.

A number of fungicides were compared for the control of mildew in commercial greenhouses. Sulfur, when used as a dust, proved ineffective. Good control was obtained with the five different wettable sulfurs and the one copper material tested when these materials were used in a protective-spray program in combination with IN 438 at a concentration of 1 : 1000. Marked differences between these and other materials occurred when they were used in an eradicant-spray program. Malachite green gave the best control although it caused some discoloration of the blossoms. Cuprocide 54 was relatively ineffective when used as an eradicant. Excellent

mildew control but severe foliage injury resulted in plots sprayed with four different soluble sulfurs. No burning and good control resulted when particulate sulfurs were used. Excellent mildew control was obtained when R.S. 380, a thiocyanate-containing material, was used in an eradicant-spray program.

The relative effectiveness of wetting agents as spray supplements for mildew control was studied. Data are presented to show that surface tension and contact-angle measurements, when used as criteria of wetting, do not always rate wetting agents in the same order. A method of measuring the contact angles of drops of liquids on rose leaves is described, and the contact angles of 40 materials on rose leaves are compared by this method. The age of the leaf, the surface of the leaf, and the variety of rose leaf used, were all found to affect contact-angle measurements. In general, the contact angles on Talisman rose leaves were smaller than those on leaves of Better Times, Hollywood, Briarcliff, White Killarney, and Queen Mary. Also the lower surface of the leaves of all varieties is, in general, more difficult to wet. When rose leaves first unfold, they are not especially difficult to wet, but become increasingly so up to the sixth day, after which the leaves gradually become easier to wet.

Marked differences in toxicity, as measured by spore-germination tests, were found when fifteen spray supplements were compared. IN 181 was the most toxic supplement of those tested. When these supplements were compared in combination with the same particulate sulfur in each test in an eradicant-spray program under commercial-greenhouse conditions, striking differences in mildew control occurred. Good control was obtained when Vatsol OT, IN 438, IN 181, and Grasselli Spreader Sticker were used as the spray supplements. These differences were considered to be due partly to variations in the wetting of the foliage and partly to variations in the toxicity of the supplements to the pathogen. Such differences did not occur when the materials were applied in a protective-spray program.

A preliminary study was made of sulfur vaporization for the control of mildew. It was found that although not enough sulfur was deposited on the leaves of rose plants to inhibit spore germination, only 6.8 per cent of the lesions remained active after a three-day exposure to sulfur vaporized at 112° to 115°C., while 77.4 per cent of the lesions remained active after a similar three-day exposure to sulfur vaporized at 85°C.

The effect of syringing on the control of powdery mildew was determined in a commercial greenhouse of badly infected Yellow Joanna Hill roses. Replicated plots were syringed once, twice, three times, and six times per week for four weeks. At the end of the experiment the average number of mildew lesions per replicated plot was 430.50, 312.75, 292.25, and 112.50, respectively. These data show that a considerable reduction in the amount of mildew can be obtained by syringing.

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APPENDIX

SOURCES AND COMPOSITION OF MATERIALS USED IN THIS STUDY

1. Ammoniacal copper carbonate. A mixture containing one ounce of copper carbonate and ten ounces of concentrated ammonium hydroxide in ten gallons of water. This formula was given by Massey (1922), p. 85.
2. Ansul Colloidal Sulphur. A wettable sulfur paste containing 70 to 75 per cent of sulfur; from the Ansul Chemical Company, Marinette, Wisconsin.
3. Areskap 50. A wetting agent containing 50 per cent of sodium sulfonate butylhydroxyphenylbenzenesulfonate in water; from the Rubber Service Laboratories Division of the Monsanto Chemical Company, Akron, Ohio.
4. Aresket 240. A wetting agent containing 40 per cent of diphenyl butyl sodium sulfonate in water; from the Monsanto Chemical Company.
5. Aresklene 375. A wetting agent containing 75 per cent of the sodium salt of a sulfonated diphenyl compound in water; in paste form from the Monsanto Chemical Company.
6. Aresklene 400. This wetting agent is the same as Aresklene 375, except that it is a powder containing one hundred per cent of the active ingredient; from the Monsanto Chemical Company.
7. Bouisol White Oil Emulsion. A copper oxychloride (25 per cent) in a white oil emulsion (75 per cent); from the Boots Pure Drug Company, Nottingham, England.
8. Crystal Mildew Spray. A soluble sulfur solution; from the Crystal Soap and Chemical Company, 6300 State Road, Philadelphia, Pennsylvania.
9. Cuprocide 54. A powder composed of 55 per cent of cuprous oxide and 45 per cent of inert ingredients; from the Röhm and Haas Company, 222 West Washington Square, Philadelphia, Pennsylvania.
10. Cyclonox. A liquid insecticide containing 70 per cent of an alkylated cyclohexylamine derivative and 30 per cent of inert ingredients; from the Niagara Sprayer and Chemical Company, Middleport, New York.
11. Dreft. A soap containing 32 per cent of sodium lauryl sulfate and 54 per cent of sodium sulfate; from Proctor and Gamble, Cincinnati, Ohio.
12. Eau Céleste. The formula used consisted of 2 pounds of copper sulfate, 1½ pints of concentrated ammonium hydroxide, and 2½ pounds of sodium carbonate in 22 gallons of water.
13. Flotation sulfur. A paste containing 40 per cent of "flotation" sulfur, "Thylox" type; from the Rochester Gas and Electric Company, Rochester, New York.
14. Fungisul. A wettable sulfur paste containing 70 per cent of sulfur, 65 per cent of which had a particle size of less than 10 microns and 35 per cent of which had a particle size of 1 micron or less — as stated by the manufacturer; from the Naugatuck Chemical Division of the United States Rubber Company, Naugatuck, Connecticut.
15. Goulac. A spray supplement which is sulfite lye, a by-product of the paper pulp industry; from the Robeson Process Company, 500 Fifth Avenue, New York City, and also (as "Bindarene") from the International Paper Company, 100 East 42d Street, New York City.
16. Grasselli Spreader Sticker. A combination wetting agent and sticker containing 35 per cent of sodium oleyl sulfate and 40 per cent of a synthetic resinous material of plastic nature; from the E. I. duPont de Nemours Company, Wilmington, Delaware.

17. Green Kolodust. A sulfur dust which is a fused bentonite-sulfur mixture containing 90 per cent of sulfur and 10 per cent of inert materials; the mixture is colored green by a dye; from the Niagara Sprayer and Chemical Company, Middleport, New York.
18. Helione Orange. A fungicide containing an orange nitro dye plus a wetting agent; from the Standard Agricultural Chemicals, Hoboken, New Jersey.
19. Helione Yellow. This fungicide contains a yellow nitro dye plus a wetting agent; from the Standard Agricultural Chemicals.
20. IN 181. A wetting agent containing approximately 72 per cent of sodium lauryl sulfate; from the Grasselli Chemicals Department of the E. I. DuPont de Nemours and Company, Wilmington, Delaware.
21. IN 181P. This wetting agent contains approximately one-half as much sodium lauryl sulfate as is present in IN 181, plus an inert powder; from the E. I. DuPont de Nemours and Company.
22. IN 438. A liquid wetting agent containing 64 per cent of sodium oleyl sulfate; from the E. I. DuPont de Nemours and Company.
23. Kainit. A crude potassic fertilizer containing approximately 35 per cent of potassium sulfate, 24 per cent of magnesium sulfate, 19 per cent of magnesium chloride, and 22 per cent of water.
24. Ko-Sul. A wettable sulfur paste containing 55 per cent of sulfur which is said by the manufacturer to have an average particle size of one micron; from the Dye-Col Products, 565 Fifth Avenue, New York City. This material is similar to Protex Colloidal Sulphur and to Walcolized Sulphur.
25. Lethane Spreader. A wetting agent consisting of a 10-per-cent aqueous solution of sulfated phenolic amines; from the Röhm and Haas Company, 222 West Washington Square, Philadelphia, Pennsylvania.
26. Malachite green. A green dye. In this study the oxalate form was used; this is sold under the trade name Victoria Green WB Crystals; from the National Aniline and Chemical Company, 40 Rector Street, New York City.
27. "Mike" Wettable Sulfur. A powder containing 95 per cent of sulfur; from the Dow Chemical Company, Midland, Michigan.
28. Moytol. A wetting agent containing 100 per cent of an alkyl aromatic sulfonate; from the Standard Chemical Products, 13th and Adams Streets, Hoboken, New Jersey.
29. Nopoco Monosulph Wetting Agent. A sulfonated castor oil; from the National Oil Products Company, Harrison, New Jersey.
30. Nopoco 1288. A sulfonated fish oil; from the National Oil Products Company, Harrison, New Jersey.
31. Nursery Volck. An insecticide consisting of 80 per cent by weight of petroleum oils and 20 per cent by weight of inert ingredients; from the California Spray Chemical Corporation, Richmond, California.
32. Organic Fungicide No. 20. A paste containing 35 per cent of the active ingredient; from the Naugatuck Chemical Division of the United States Rubber Company, Naugatuck, Connecticut.
33. Ortho Mildew Spray. A petroleum oil emulsion; from the California Spray Chemical Company, Richmond, California.
34. Palustrex Sulfonate-B. A fungicide consisting of pine oil with sulfonated castor oil as the emulsifying agent and containing 15 per cent of copper resinate; from the Southern Pine Chemical Company, Jacksonville, Florida.
35. Penetrol. A wetting agent containing 90 per cent of sulfonation products of "oxidized" petroleum oil; from Kay-Fries Chemicals, 180 Madison Avenue, New York City.
36. Phenothiazine. An insecticide containing a wetting agent; from the Dow Chemical Company, Midland, Michigan.
37. Pomo-Green. A fused green bentonite-sulfur dust containing 80 per cent of sulfur, 10 per cent of lead arsenate, and 10 per cent of inert materials; from the Niagara Sprayer and Chemical Company, Middleport, New York.
38. Protex Colloidal Sulphur. A wettable sulfur paste containing 50 per cent of sulfur, the particle size of which is said by the company to average one micron; from the Protex Industries, 500 Fifth Avenue, New York City. This material is similar to Ko-Sul and to Walcolized Sulphur.

39. Pyrolene M. P. A wetting agent containing an alkyl aromatic sulfonate plus a fatty acid amide sulfonate; from the Standard Agricultural Chemicals, Hoboken, New Jersey.
40. Righto. An insecticide containing rotenone with a kerosene oil base; from the Plantspur Products Company, Ridgefield, New Jersey.
41. Rosin mixture. A wetting agent consisting of 5 parts of E grade rosin, 1 part of potassium hydroxide, and 14 parts of water as recommended by Yarwood (1937).
42. R. S. 380. An insecticide containing an oil together with a thiocyanate; from the Röhm and Haas Company, 222 West Washington Square, Philadelphia, Pennsylvania.
43. Santomerse D. A wetting agent containing 100 per cent of a sulfonic acid of an aromatic hydrocarbon; from the Rubber Service Laboratories Division of the Monsanto Chemical Company, Akron, Ohio.
44. Santomerse S. A 30-per-cent solution of the above material.
45. S. E. C. Oil. A self-emulsifying oil containing 90 per cent of cottonseed oil; from the Röhm and Haas Company, 222 West Washington Square, Philadelphia, Pennsylvania.
46. Selocide Concentrate. A 30-per-cent aqueous solution of potassium-ammonium-seleno sulfide; from the McLaughlin-Gormley-King Company, 1715 Fifth Street, S.E., Minneapolis, Minnesota.
47. Shirlan D. A fungicide containing salicyl anilide and a sulfonated wetting agent; from the Organic Chemicals Department of E. I. DuPont de Nemours and Company, Wilmington, Delaware.
48. Silver mixture. The mixture, as suggested by L. W. Nielsen, contained 7.15 grams of silver nitrate, 45.4 grams of manganese sulfate, and 75.7 grams of calcium hydroxide, in 12 gallons of water.
49. Sodium abietate. A resin derivative; from the Paper Makers Chemical Corporation of Kalamazoo, Michigan.
50. Sodium oleate. A wetting agent prepared in the laboratory by mixing equivalent parts of sodium hydroxide and oleic acid.
51. Soybean oil plus cuprous oxide. The sample used contained 25 per cent by weight of colloidal red copper oxide and about 50 per cent of soybean oil which was partially emulsified; from the Terra Chemical Company, 512 Greenwich Street, New York City.
52. SS_8, SS_9, and SS_{10}. Experimental wetting agents; from the E. I. DuPont de Nemours and Company, Wilmington, Delaware.
53. Stantex Wetter No. 20. A wetting agent containing an aliphatic alcohol sulfate; from the Standard Agricultural Chemicals, Hoboken, New Jersey.
54. Sulfocide. A soluble sulfur mixture containing 34 per cent of sodium sulfide, 0.67 per cent of sodium thiosulfate, and 0.15 per cent of sodium sulfate; from the B. G. Pratt Company, 50 Church Street, New York City.
55. Sulfocol. A wettable sulfur containing a wetting agent and 45 per cent of sulfur; the sulfur particle size averaged three to four microns as stated by the manufacturer; from the Standard Agricultural Chemicals, Hoboken, New Jersey.
56. Sulfur-rosin mixture. This mixture, as recommended by Newton and Hastings (1930), was prepared with a ratio of 4 pounds of sulfur, 4 pounds of rosin, 7 pounds of potassium hydroxide, and 1 pound of water. Sufficient heat was generated to fuse the mixture.
57. Tergitol No. 7. A wetting agent containing a sodium secondary alcohol sulfate; from the Carbide and Carbon Chemicals Corporation, 30 East 42d Street, New York City.
58. Triethanolamine oleate. A wetting agent prepared in the laboratory by mixing equivalent proportions of triethanolamine and oleic acid.
59. Ultrawet. A wetting agent that was a water soluble monosulfonate of petroleum hydrocarbons having an average of 16 carbon atoms in the hydrocarbon molecules; from the Hammond Paint and Chemical Company, Beacon, New York.
60. Vatsol OS. A dry wetting agent containing 95 per cent of sodium alkylated naphthalene sulfonate and 5 per cent of inert ingredients; from the Insecticide Department of the American Cyanamid and Chemical Corporation, 30 Rockefeller Plaza, New York City.
61. Vatsol OT. A dry wetting agent containing 100 per cent of a sodium alkyl ester of sulfosuccinate; from the American Cyanamid and Chemical Corporation.

62. Vatsol OTC. A dry wetting agent containing 10 per cent of Vatsol OT and 90 per cent of an inert neutral water-soluble filler; from the American Cyanamid and Chemical Corporation.
63. Walcolized Sulphur. A wettable "colloidal" sulfur paste containing 50 per cent of sulfur; similar to Ko-Sul and to Protex Colloidal Sulphur; from the Walco Products, 512 Greenwich Street, New York City.

The information regarding the proprietary materials listed was obtained from the following sources:

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3. Correspondence and literature from the manufacturers concerned.
4. Labels on the containers.